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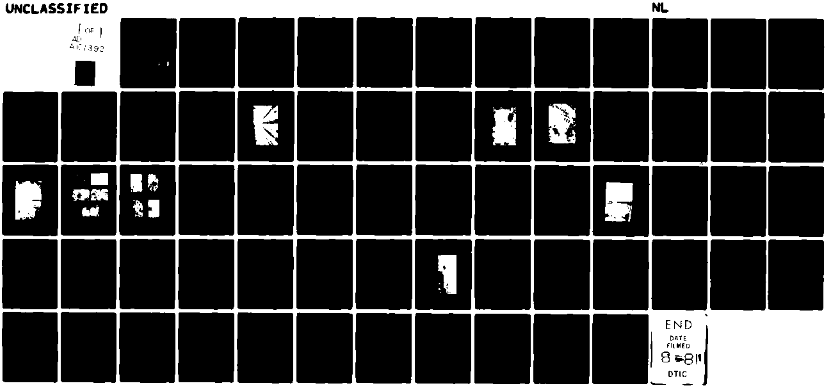

LEVEL III

AD A101392

STREAM CHANNEL STABILITY

APPENDIX G

SOIL EROSION AND SEDIMENT CHARACTERISTICS OF TYPICAL SOILS AND LAND USES IN THE GOODWIN CREEK CATCHMENT

Project Objectives 3 and 4

by

L. D. Meyer and W. C. Harmon

USDA Sedimentation Laboratory
Oxford, Mississippi

April 1981

Prepared for
US Army Corps of Engineers, Vicksburg District
Vicksburg, Mississippi

Under
Section 32 Program, Work Unit 7

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PREFACE

Well over half the sediment lost from many watersheds originates as eroded soil from their uplands and bottomlands. Such erosion occurs over such a large area that it often goes unnoticed in comparison to the more spectacular losses from stream channels and gullies, yet it may be an even greater sediment source. Of course, upland erosion is sometimes quite noticable when rilling occurs at serious rates, but the "unseen" interrill erosion, caused primarily by raindrop impact on land between rills and gullies, may also produce great quantities of sediment. Interrill erosion cannot be evaluated by field observations or cross-section measurements, so this research was conducted to study interrill erosion rates for the major soils and land uses in Goodwin Creek Watershed.

Results from hundreds of simulated rainstorms ~~that were~~ applied on many different soils and cropping conditions, showed that the soils of Goodwin Creek Watershed are among the most erodible in Mississippi. More interrill erosion occurred from these soils during an hour of moderately intense rainfall than is considered tolerable per year when they were exposed to rainfall without crop cover. However, erosion decreased greatly as cover developed during the progressive stages of a cotton crop year. Erosion from land in soybeans was similar to that from land in cotton, but good pasture and woodland had interrill erosion rates that were relatively insignificant.

Not only are the soils of the Goodwin Creek area very erodible, but the resulting sediment was found to be very easily transported. Well over half the sediment from the major soils was smaller than sand-size (< 50 μm), and such sediment is readily carried by runoff. Since this finer sediment is more difficult to trap, it moves farther through the flow system before depositing.

The transport of sediment was studied for various conditions that are typical of intensively cropped land to evaluate how much sediment would be carried from the sources to the major stream systems. The capacity of runoff to transport sediment was affected most by the steepness of the runoff flow channel. Steepnesses exceeding 1% could transport large quantities of sediment. Transport capacity also increased rapidly as flow rate increased and as sediment size decreased.

This research has emphasized what was evident from careful field observations--that Goodwin Creek Watershed soils are very erodible, that the resulting sediment is readily transported, and that the topography of the land is conducive to delivering much of the sediment to the watershed stream systems. The data upon which these findings are based and discussions of the results are given in the following material.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U.S. CUSTOMARY UNITS OF MEASUREMENT[1/]

Units of measurement used in this report can be converted as follows:

To convert	To	Multiply by
mils (mil)	micron (μm)	25.4
inches (in)	millimeters (mm)	25.4
feet (ft)	meters (m)	0.305
yards (yd)	meters (m)	0.914
miles (miles)	kilometers (km)	1.61
inches per hour (in/hr)	millimeters per hour (mm/hr)	25.4
feet per second (ft/sec)	meters per second (m/sec)	0.305
square inches (sq in)	square millimeters (mm^2)	645.
square feet (sq ft)	square meters (m^2)	0.093
square yards (sq yd)	square meters (m^2)	0.836
square miles (sq miles)	square kilometers (km^2)	2.59
acres (acre)	hectares (ha)	0.405
acres (acre)	square meters (m^2)	4,050.
cubic inches (cu in)	cubic millimeters (mm^3)	16,400.
cubic feet (cu ft)	cubic meters (m^3)	0.0283
cubic yards (cu yd)	cubic meters (m^3)	0.765
cubic feet per second (cfs)	cubic meters per second (cms)	0.0283
pounds (lb) mass	grams (g)	454.
pounds (lb) mass	kilograms (kg)	0.453
tons (ton) mass	kilograms (kg)	907.
pounds force (lbf)	newtons (N)	4.45
kilogram force (kgf)	newtons (N)	9.81
foot pound force (ft lbf)	joules (J)	1.36
pounds force per square foot (psf)	pascals (Pa)	47.9
pounds force per square inch (psi)	kilopascals (kPa)	6.89
pounds mass per square foot (lb/sq ft)	kilograms per square meter (kg/m^2)	4.88
U.S. gallons (gal)	liters (L)	3.79
quart (qt)	liters (L)	0.946
acre-feet (acre-ft)	cubic meters (m^3)	1,230.
degrees (angular)	radians (rad)	0.0175
degrees Fahrenheit (F)	degrees Celsius (C)[2/]	0.555

2/ To obtain Celsius (C) readings from Fahrenheit (F) readings, use the following formula: C = 0.555 (F-32).

Metric (SI) to U.S. Customary

To convert	To	Multiply by
micron (μm)	mils (mil)	0.0394
millimeters (mm)	inches (in)	0.0394
meters (m)	feet (ft)	3.28
meters (m)	yards (yd)	1.09
kilometers (km)	miles (miles)	0.621
millimeters per hour (mm/hr)	inches per hour (in/hr)	0.0394
meters per second (m/sec)	feet per second (ft/sec)	3.28
square millimeters (mm^2)	square inches (sq in)	0.00155
square meters (m^2)	square feet (sq ft)	10.8
square meters (m^2)	square yards (sq yd)	1.20
square kilometers (km^2)	square miles (sq miles)	0.386
hectares (ha)	acres (acre)	2.47
square meters (m^2)	acres (acre)	0.000247
cubic millimeters (mm^3)	cubic inches (cu in)	0.0000610
cubic meters (m^3)	cubic feet (cu ft)	35.3
cubic meters (m^3)	cubic yards (cu yd)	1.31
cubic meters per second (cms)	cubic feet per second (cfs)	35.3
grams (g)	pounds (lb) mass	0.00220
kilograms (kg)	pounds (lb) mass	2.20
kilograms (kg)	tons (ton) mass	0.00110
newtons (N)	pounds force (lbf)	0.225
newtons (N)	kilogram force (kgf)	0.102
joules (J)	foot pound force (ft lbf)	0.738
pascals (Pa)	pounds force per square foot (psf)	0.0209
kilopascals (kPa)	pounds force per square inch (psi)	0.145
kilograms per square meter (kg/m^2)	pounds mass per square foot lb/sq ft)	0.205
liters (L)	U.S. gallons (gal)	0.264
liters (L)	quart (qt)	1.06
cubic meters (m^3)	acre-feet (acre-ft)	0.000811
radians (rad)	degrees (angular)	57.3
degrees Celsius (C)	degrees Fahrenheit (F)3/	1.8

1/ All conversion factors to three significant digits.

3/ To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following formula: $F = 1.8C + 32$.

SOIL EROSION AND SEDIMENT CHARACTERISTICS
OF TYPICAL SOILS AND LAND USES IN
THE GOODWIN CREEK CATCHMENT

L.D. Meyer and W.C. Harmon

1 INTRODUCTION

Much of the sediment moving through major streams originates as eroded soil from contributing agricultural areas, particularly those that are intensively cropped (Figure 1). Such sediment is detached and transported by the rainfall and runoff that result from moderate to intense rainstorms on upland areas that are not adequately protected from the erosive forces of raindrops and flowing water. Different soils may vary considerably in their rate of erosion due to inherent textural and structural differences. Such differences may also affect sediment characteristics, particularly size distribution and density, which in turn affect the transportability of the sediment once it is detached. In addition to soil differences, the type and amount of vegetative cover on the land and the topographic characteristics of the land can greatly influence the rate of sediment production and transport during rainstorms. The research conducted during this study was designed to investigate the range of erodibilities for the various soils in the Goodwin Creek Watershed, the effect of different land uses and cropping systems on erosion, the change in erosion rates at different stages of crop growth, the size distributions of sediment from different soils and soil conditions, and the sediment transport capacities of runoff along crop rows of various lengths and steepnesses for different sediment sizes.

Figure 1 Soil erosion of intensively cropped land often produces much of the sediment entering stream channels.

LITERATURE SURVEY

2

Soil erosion by water is the detachment and transportation of soil particles by rainfall and runoff. Excessive soil erosion has historically caused disastrous consequences to the once-productive land of many nations (Bennett, 1939; Lowdermilk, 1950). It is a serious problem on more than half the 180 million hectares of cropland in the United States (USDA, 1965) and on a similar area of forest, pasture, and rangeland. Soil eroded from such upland areas is the source of much of the sediment transported to rivers and reservoirs.

Erosion of agricultural land was once considered primarily the farmer's problem, because excessive erosion generally decreases the productive potential of cropland. However, equally serious problems often develop after eroded soil leaves upland areas, since it then may muddy streams, clog rivers, and fill reservoirs. Thus, eroded soil frequently does triple damage; first, where it originates; second, when in transit; and third, where it deposits.

The companion processes of soil erosion and sedimentation involve complex interrelationships among the many factors that influence detachment, transportation, and deposition of soil particles by rainfall and runoff. This erosion process usually begins when raindrops strike unprotected soil on the earth's surface and detach soil particles (Ekern, 1950; Mihara, 1951). In areas where the annual rainfall is about 1 meter, several trillion raindrops, falling at speeds up to 9 m/s, annually bombard each hectare of land. This amount of water has a volume of 10,000 m^3, a mass of about 10 million kg, and falls with an impact energy of 200 to 300 million joules. Unless the soil surface is protected by vegetation, mulch, or other cover, these raindrops detach tremendous quantities of soil from the soil mass. In addition, the outward splash when the drops strike exposed soil on sloping land will cause net movement downslope. The rate of soil detachment and net downslope movement by rainfall depend on soil characteristics, surface condition, slope steepness, and rainfall characteristics (Ellison, 1947; Ekern, 1950).

Most soil eroded by water is transported downslope by surface runoff. Runoff does not begin, however, until the rain intensity exceeds the infiltration rate of the soil and the surface storage capacity of the land

has been satisfied. Thus, soil conditions with high intake rates or large surface ponding capacities may appreciably delay runoff and reduce subsequent runoff and erosion rates.

Once runoff begins, the quantity and size of material that it can transport depend on runoff velocity and turbulence (ASCE, 1975), and these increase as the slope steepens and the flow increases. The larger and denser the eroding material, the greater must be the flow velocity and turbulence to transport it. Major rates of runoff can usually transport all rainfall-detached soil and, in addition, detach soil by hydraulic shear and transport it downslope.

Soil eroded from upland slopes comes from (a) <u>interrill areas</u> (those parts of the land surface between runoff channels), (b) <u>rills</u> (eroded channels that can be obliterated by subsequent tillage), and (c) <u>gullies</u> (eroded channels that are major features of the surface drainage topography). Interrill erosion is a relatively uniform removal of soil, so it is not so visually noticeable as is rill or gully erosion. It results primarily from the effects of raindrop impact, and it includes both movement by splash and transport of raindrop-detached soil by a thin-film runoff. On land where the soil surface is not protected by cover, much of the soil lost is by interrill erosion. The interrill erosion rate is not greatly affected by the steepness of the interrill surface (Lattanzi, et al., 1974; Meyer et al., 1975b) or, since rainfall impact is relatively uniform all over an area of land, the location on the land slope.

Rill erosion results primarily from soil detachment by concentrated runoff. It usually occurs on only a limited percentage of the land surface. Rill erosion is much more intensive and noticeable than interrill erosion. Rills may develop where runoff is concentrated by topographic variations, tillage marks, or random irregularities on the land surface. However, concentrated flow does not cause rill erosion until the flow's shear forces exceed the soil's resistance to them. Thus, concentrated runoff may flow for a considerable distance downrow or downslope before rilling starts (Meyer and Monke, 1965), and deposition of soil from interrill areas rather than erosion by rilling may occur along the upper portions of such channels (Meyer et al., 1980).

Gullies develop from massive soil erosion by concentrated runoff. Gully erosion characteristically proceeds upslope as a series of large headcuts (Piest and Bowie, 1974; Leopold, et al., 1964).

The relative contributions from interrill areas, rills, and gullies to the total erosion depend on the slope length and vary with climatic and soil conditions (Meyer et al., 1976). Although the amount of sediment originating from rills and gullies may be estimated from observations or measurements, the erosion from interrill areas must either be evaluated experimentally or predicted from known soil, rainfall, and crop cover characteristics. Prediction techniques are not currently available.

The erodibilities of different soils vary because soils differ in particle size distribution, cohesiveness, and aggregate strength. The physical and chemical properties of cohesive soils greatly affect their erodibility (Partheniades, 1971). Since soil is often eroded as aggregates, the larger sizes of the aggregates as compared to their primary particles are important characteristics affecting erodibility. Sediment that is eroded as aggregates may have the transportability characteristics of sand or even gravel although consisting mostly of silt and clay materials.

Generally, cohesive or fine-textured soil materials are less easily detached from the soil mass than noncohesive soil materials. Coarse-textured soil materials are not held as strongly to the soil mass by cohesion, but they usually have greater rain-intake rates and thus less runoff. The net result is that the medium-textured soils such as loams and silt loams are generally more erodible than soils with high clay or high sand contents because the silty soils are susceptible to surface sealing and are also more readily detached and transported (Wischmeier and Mannering, 1969).

The extent to which soil surfaces are protected by vegetation, mulches, or other cover greatly influences their susceptibility to erosion by rainfall and runoff. Such covers dissipate raindrop impact energy and slow the velocity of runoff. When the soil surface is well protected with surface mulch or canopy cover, interrill erosion may be essentially eliminated (Lattanzi, et al., 1974), and rill erosion may be appreciably decreased (Meyer, et al., 1975a). Surface cover also greatly affects erosion by slowing runoff velocity. Growing vegetation acts as a pump that removes soil water from the root zone and thus provides greater storage potential for subsequent precipitation.

Seldom is all eroded soil lost from a field or watershed, because some is usually redeposited within the area (Figure 2). Deposition occurs when the runoff can no longer carry all of its sediment load, usually because of decreased slope steepness or increased density of vegetative cover. Such deposition is a selective process, with the largest and/or densest material settling out first and the finer materials being carried farther by the runoff (Stallings, 1953). Therefore, the size distribution of the eroded sediment is important in determining the portion of the sediment load that is deposited and the size distribution of the remaining sediment load.

Since part of the eroded soil deposits somewhere downslope, the sediment yield from a land area or watershed is less than the total gross erosion from all sediment sources. The ratio of sediment yield to gross erosion for an area is known as the "sediment-delivery ratio". Clearly, the sediment-delivery ratio for a given watershed depends on transportability characteristics of the sediment such as size and density and on the opportunities for sediment deposition within the watershed.

Accurate predictions of soil-erosion rates for specific conditions and land uses are important for determining sediment losses and for designing erosion-control practices. The Universal Soil Loss Equation (Wischmeier and Smith, 1978; Wischmeier, 1976) is the most widely used technique for estimating upland erosion. It incorporates the six major factors that affect upland soil erosion by water: rainfall erosiveness, soil erodibility, slope length, slope steepness, cropping and management techniques, and supporting conservation practices. It is a statistically derived mathematical model designed for use by land-management planners to estimate erosion rates for a wide range of rainfall, soil, slope, crop, and management conditions and to select alternative land-use and practice combinations that will limit erosion rates to acceptable levels. This equation estimates the average annual erosion rate for specific field conditions. It was not meant to be used for predictions of individual storm losses. It does not estimate sediment yields at points downslope from upland areas if deposition occurs between the sediment source and the point of measurement. It also does not include gully erosion, erosion along streambanks, or wind erosion.

Mathematical models that more fully incorporate the physical processes involved in erosion and sedimentation and are suitable for evaluations of

Figure 2 Some of the eroded soil, generally the coarser material, may deposit within a field or watershed with the remaining finer material being carried by the runoff into the stream system.

individual storms have been developed in recent years. These include models that separate the upland erosion process into components of detachment by rain, transport by rain, detachment by runoff, and transport by runoff, with appropriate considerations of component interrelationships (Meyer and Wischmeier, 1969; Rowlison and Martin, 1971); those that separate a soil's interrill erodibility from its rill erodibility and consider the relative contributions for different slope lengths, slope steepnesses, and cover conditions (Meyer et al., 1975a; DeCoursey and Meyer, 1976; Foster et al, 1977); those that consider sediment size and density characteristics plus runoff hydraulics in evaluating sediment yield and sediment sizes from grass buffer strips, graded terraces, impoundment terraces, and sediment basins (Foster, et al., 1980; Laflen, et al., 1978); and those that evaluate the influence of different row spacings, crop canopy development, row gradient, and tillage pattern on runoff, erosion, and other characteristics (DeCoursey, 1980). These and other comprehensive models are beginning to be used for evaluations of soil erosion, sedimentation, and related characteristics.

Soil erosion rates and sediment characteristics for land in the Goodwin Creek Watershed or nearby have not been experimentally evaluated heretofore. Most of these soils were developed from wind-blown, predominantly silt-textured loess (USDA - SCS, 1963). The loess was deposited thousands of years ago in depths greater than 1 meter over most of this area, although it is now shallower in many places because of subsequent erosion by rainstorms. Much of this eroded material has been redeposited on bottomland fields that are often cropped intensively. Thus, soils are predominantly of a silt texture, although some bottomlands that include major amounts of sediment eroded from sandy subsoils underlying the loess have considerable sandy soil material. As indicated earlier, silty soils are generally very erodible.

Research on similar deep loess bluffline watersheds in Iowa (Piest and Spomer, 1968; Piest and Bowie, 1974) have shown that well over half the sediment from such land generally originates from the agricultural uplands, even though gully and streambank erosion are very severe. Other results from the Pigeon Roost Watershed (Bowie, 1980), about 50 miles northeast of the Goodwin Creek Watershed, also show that sediment in streams originates predominantly from upland agricultural areas. Such results indicate that

erosion from upland agricultural land is a major contributor to the sediment moving through stream channels of the Goodwin Creek Watershed and that the control of such erosion is essential to significant reductions in the total sediment load, even though gully and stream channel erosion are very serious and more spectacular in this watershed.

Evaluations of erosion rates from different soils, land uses, and cover conditions and of sediment characteristics that influence sediment transportability and ease of deposition were primary goals of this phase of research. Related research was conducted to evaluate the rate of sediment transport and thereby to provide an indication of the movement of eroded sediment through upland flow systems, especially on cropped fields. Emphasis in this research was on conditions where intensive cropping exposes soil to the forces of rainfall and runoff.

3 RESEARCH RESULTS

3.1 SOIL EROSION

The rate of interrill erosion resulting from a wide range of rainstorm intensities was evaluated for major land use conditions in the Goodwin Creek Watershed. Research was conducted on typical field conditions using sites selected cooperatively by researchers and a SCS soil scientist.

A major source of sediment from agricultural land during erosive rainstorms is the soil eroded from row sideslopes of land in rowcrop production and from other interrill areas. On most cropped fields, the soil surface is exposed to raindrop impact until covered by plant canopy or residues. The sediment from the row sideslopes may be transported along the rill furrows to major water courses and streams, or it may be partially deposited somewhere between. The goal of this phase of research, however, was to evaluate the rate of sediment production from row sideslopes and other interrill areas.

3.1.1 Procedure

Soil erosion data can be obtained more rapidly and efficiently by using simulated rainfall than by relying on natural rainfall. A new rainfall simulator (Figure 3) was developed with the capability of applying rainstorms at a wide range of intensities and with kinetic energies of impact very near those of natural rainstorms (Meyer and Harmon, 1979). Plots were the width of crop rows (about 1 meter) by 0.9 meters along the row (Figure 4). A small trough was installed in the center of the rill furrow to collect the runoff from the row sideslopes for all conditions except the pasture and woodland sites, where the trough was placed along the lower edge of the plot. All runoff from the plots was collected, generally at intervals of 3 to 5 minutes. Runoff samples were weighed immediately, and then they were transferred to the Sedimentation Laboratory to dry and weigh the sediment portion of the runoff and thereby determine erosion rates.

The multiple-intensity rainfall simulator has the capability to apply any of dozens of intensities from less than 10 to more than 100 millimeters per hour, but most studies were conducted at intensities of about 10, 25, 67, and 105 mm/hr. The standard sequence of simulated rainstorms is given in Table 1. The 60- and 30-minute storms of moderate intensity were applied to evaluate erosion under dry initial conditions and then wet

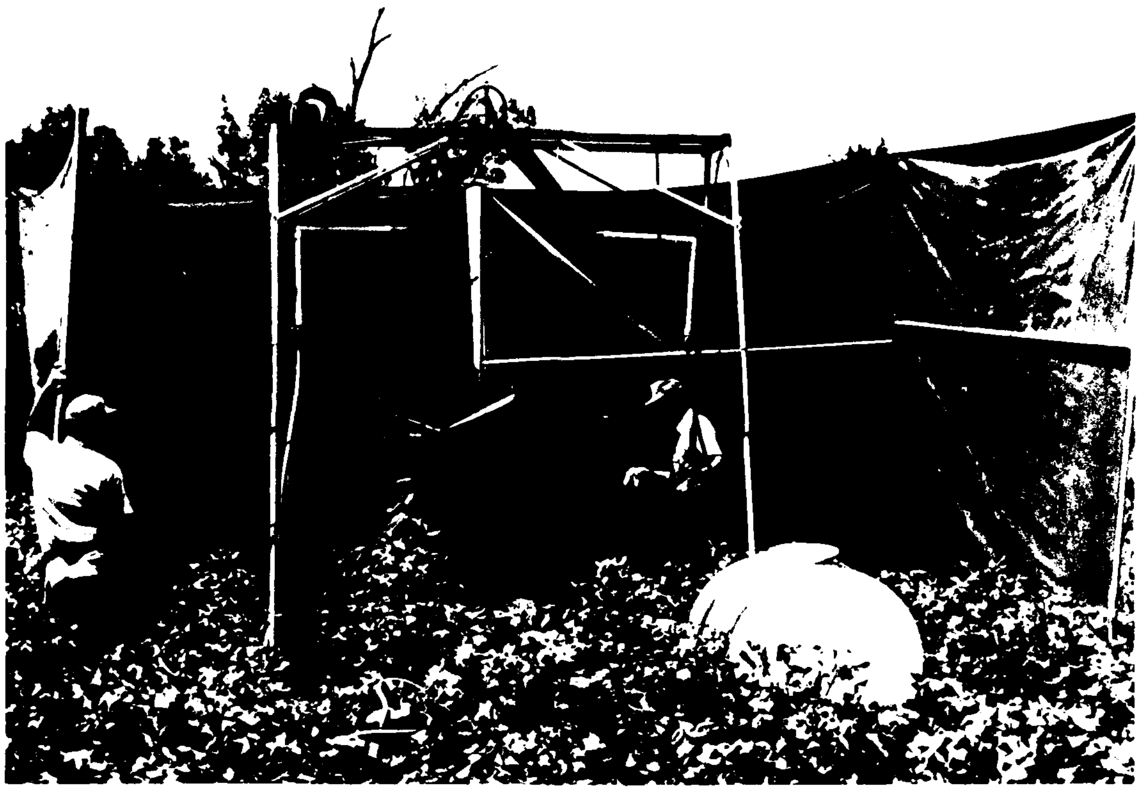


Figure 3 Multiple-intensity rainfall simulator that was used to apply simulated rainstorms on field plots for evaluating erosion and sediment size distributions from crop row sideslopes and other interrill areas.

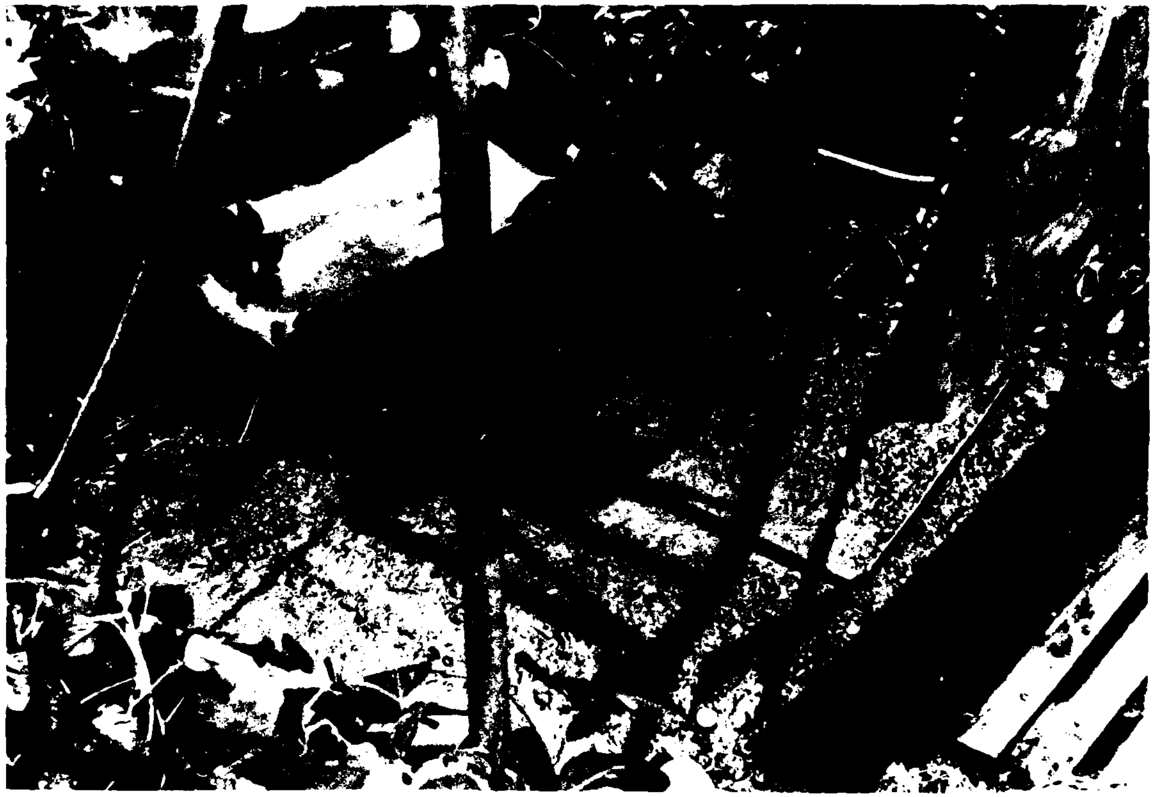


Figure 4 Typical research plot in farm field used for evaluating erosion and sediment sizes of different soils and cropping conditions.

TABLE 1.
Sequence of Simulated Rainstorms Used During Erosion Research

Storm	Approx. Time Since Previous Storm	Storm Length min.	Nominal Rep. 1 mm/h	Intensity Rep. 2 mm/h
1	-----	60	67	67
2	20 hrs.	30	67	67
3	5 min.	15	25	105
4	5 min.	15	105	25
5	5 min.	15	67	67
6	5 min.	15	105	25
7	5 min.	15	25	105
8	5 min.	15	67	67
9	5 min.	15	10	10

initial conditions the next day. The storms also standardized the moisture conditions for the 15-minute storms at the four intensities that followed. (For some conditions, the sixth, seventh, and eighth storms were omitted.) With this sequence, each of the 15-minute storms at the three higher intensities followed both of the others an equal number of times. The final storm at 10 mm/hr was only applied after all other storms were completed. Except as indicated, all treatments were studied in duplicate, and the average erosion rate during the latter part of each run was used in the analyses.

Seven soil types, representing the range of conditions found in the Goodwin Creek Watershed, were studied at a total of nine different sites. A description of each of these soils and sites is given in Table 2. To test differences in soil erodibility, soils were prepared in a bare, tilled condition by removing all plants and residues of the existing crop and cultivating the soil to a depth of 50 to 75 millimeters with a long-tined potato rake, as shown in Figure 5. The Vicksburg soil was tested at 5 major stages typical of cotton land through the year (Figure 6), and 3 of these stages were tested with and without crop canopy. In addition, typical watershed sites with pasture, woodland, and soybeans were also evaluated (Figure 7). Different plots were used for each test.

3.1.2 Results and Discussion

The erosion that occurred from row sideslopes for the different soils in a bare, tilled condition (Figure 5) are given in Table 3. The first 2 columns of data show the total amount of sediment eroded from the row sideslopes to the row furrow during the 60-minute dry run and the 30-minute wet run. The remaining columns show the erosion rates at different times during the various runs listed in Table 1. The first 3 erosion rates are at different times during the 60-minute initial run followed by the rate near the end of the 30-minute wet run the next day and then rates during the succeeding runs of 25, 67, 105, and 10 mm/hr.

The results in Table 3 show that the bottomland soils, Arkabutla, Collins, Ochlockonee and Vicksburg, were more erodible than the 3 upland soils during the 60-minute initial run. The differences were not nearly so great during the 30-minute wet run the following day. During the succeeding 15-minute runs, the upland Grenada soil had one of the higher erodibilities.

Table 2. Description of Soils Studied that are Representative of Those in the Goodwin Creek Watershed

Soil Series	Similar Soils*	Taxonomic Class	Location	Description	Cropping History
Arkabutla	Falaya	Aeric Fluvaquents Fine-silty, mixed acid, thermic	About 10 miles southeast of Oxford, MS, on flood plain	Silt loam, nearly level, somewhat poorly drained	Row crop, cotton
Collins		Aquic Udifluvents coarse-silty, mixed, acid, thermic	About 8 miles southeast of Batesville, MS, on flood plain	Silt, less than 2 percent slope, moderately well drained	Row crop, soybeans
Grenada		Glossic Fragiudalfs Fine-silty, mixed, thermic	About 7 miles south of Oxford, MS, on stream terrace	Silt loam, 1 to 3 percent slope, moderately well drained	Row crop, cotton
Loring		Typic Fragiudalfs Fine-silty, mixed, thermic	About 7 miles southeast of Batesville, MS, on loess ridge top	Silt loam, 2 to 5 percent slope, eroded, moderately well drained	Row crop, cotton
Loring		Typic Fragiudalfs Fine-silty; mixed; thermic	About 8 miles southeast of Batesville, MS, middle slope of loess hill	Silt loam, 5 to 8 percent slope, eroded, moderately well drained	Grass pasture (20 yr.); previously cropped to cotton
Loring		Typic Fragiudalfs Fine-silty, mixed, thermic	About 8 miles southeast of Batesville, MS, on lower slope of loess hill	Silt loam, 5 to 8 percent slope, moderately well drained	Woodland pasture, no known history of cultivation

(Cont'd)

Table 2 (Cont'd). Description of Soils Representative of Goodwin Creek Watershed

Soil Series	Similar Soils*	Taxonomic Class	Location	Description	Cropping History
Memphis		Typic Hapludalfs Fine-silty, mixed, thermic	About 6 miles south of Batesville, MS, on loess ridge top	Silt loam, 5 to 8 percent slope, eroded, well drained	Row crop, cotton
Ochlockonee	Mixed alluvial land	Typic Udifluvents coarse-loamy, siliceous, acid, thermic	About 5 miles west of Oxford, MS, on nearly level flood plain	Sandy loam nearly level, well drained	Row crop, cotton
Vicksburg	Collins	Typic Udifluvents coarse-silty mixed, acid, thermic	About 8 miles southeast of Batesville, MS, on flood plain	Silt loam less than 2 percent slope, well drained	Row crop, cotton

*As mapped in the Goodwin Creek Watershed area by the Panola County Soil Survey (USDA-SCS, 1963)

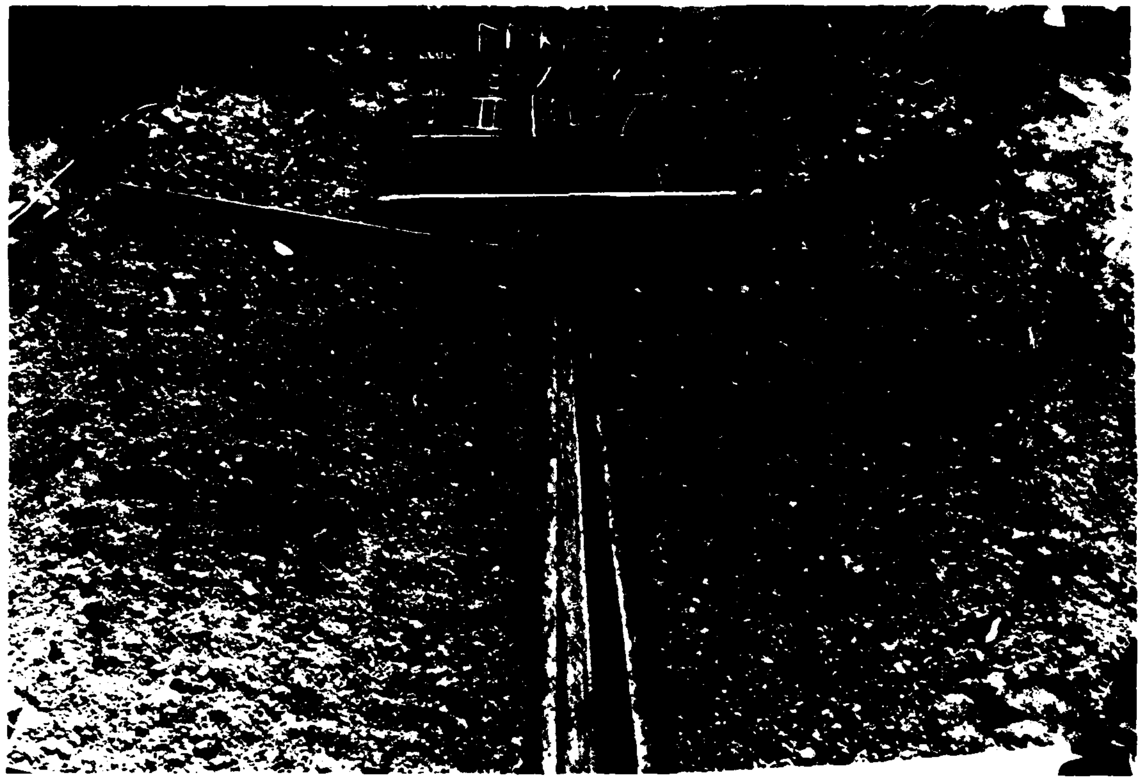
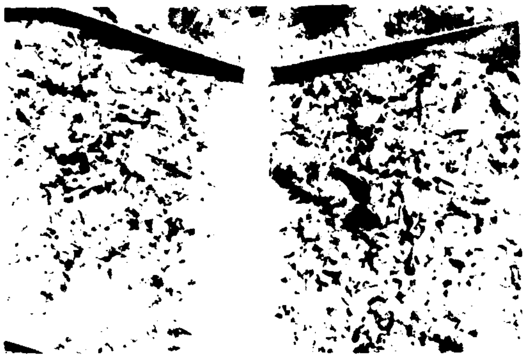


Figure 5 Typical bare, tilled plot to which rainstorms were applied for soil erodibility evaluations.



a. Bedded for planting

b. Cultivated shortly after emergence

c. Part canopy

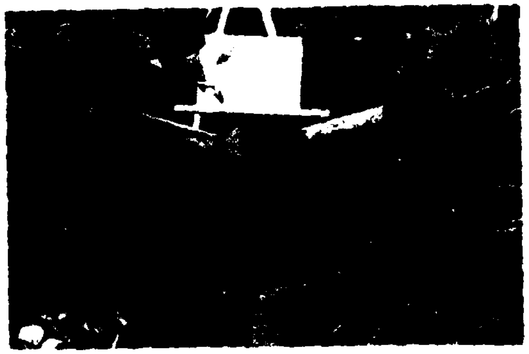
d. Full canopy

e. After harvest

Figure 6 Five major crop stages of cotton land through the year that were studied during this research.

a. Pasture

b. Woodland



c. Soybeans

d. Cotton

Figure 7 Four typical Watershed cover conditions that were studied during this research.

Table 3. Interrill Erosion of Typical Watershed Soils in a Bare, Tilled Condition for the Runs in Table 1.

Soil	Rep.	Land Use	Loss for Run (t/ha) 60 min "dry"	30 min "wet"	Erosion Rate* (t/ha-hr) D_{20}	D_{37}	D_{55}	W	L1	L2	M1	M2	H1	H2	VL
Arkabutla sil	I	Cotton	49.8	19.9	66.0	58.7	52.7	44.8	7.0	4.9	41.5	32.2	100.2	88.4	0.6
	II	Cotton	49.7	18.6	61.6	59.5	55.0	41.8	6.5	4.4	41.6	33.9	100.9	82.4	0.7
Collins silt	I**	Soybns	65.6	16.9	84.8	57.9	52.0	40.0	3.7	-	32.2	-	78.4	-	0.8
Grenada sil	I	Cotton	37.3	16.5	42.7	46.1	52.9	45.3	9.0	4.6	47.2	38.7	120.6	105.4	1.4
	II	Cotton	42.2	19.7	52.6	57.1	54.8	49.9	10.4	5.3	53.2	43.3	145.1	109.1	2.4
Loring sil	I	Cotton	31.3	11.3	31.6	30.7	32.0	27.3	5.2	3.2	28.8	22.6	55.1	57.6	0.8
	II	Cotton	36.3	9.5	43.8	40.2	38.4	22.9	3.0	3.3	27.0	22.7	63.7	57.1	0.7
Loring sil	I**	Woods	9.9	-	10.4	12.5	12.4	13.3	1.8	-	10.6	-	30.4	-	0.3
Loring sil	I**	Past.	18.6	8.9	21.4	27.1	24.7	19.3	2.9	-	17.2	-	41.1	-	0.5
Memphis sil	I	Cotton	42.8	17.5	49.3	52.1	48.8	41.5	5.9	4.1	36.3	29.6	100.9	74.9	0.6
	II	Cotton	44.0	18.3	55.1	50.3	49.2	42.7	7.0	4.7	39.5	33.8	96.3	81.5	0.7
Ochlockonee sl	I	Cotton	52.7	20.2	61.9	58.2	53.8	40.9	5.2	4.6	36.1	32.3	93.0	85.0	-
	II	Cotton	40.6	18.4	50.6	49.2	43.0	36.2	4.6	4.2	31.0	28.5	81.4	72.1	-
Vicksbg sil															
Spr bed	I**	Cotton	100.1	-	159.1	111.0	87.8	-	13.9	-	70.3	-	171.8	-	1.2
Spr plant	I	Cotton	93.9	30.2	129.5	119.7	98.7	71.5	11.6	-	67.8	-	153.8	132.8	0.8
	II	Cotton	95.8	36.6	117.7	128.5	108.4	80.2	11.5	7.4	74.9	46.6	166.1	136.4	1.0
Summer	I**	Cotton	45.1	-	60.4	52.3	44.9	-	-	-	-	-	-	-	-
Fall	I	Cotton	49.2	22.2	57.4	59.7	62.5	54.0	6.8	2.9	39.7	30.5	118.1	93.1	0.7
	II	Cotton	41.4	19.8	50.5	56.0	51.1	45.7	3.9	4.0	36.8	24.1	116.6	87.1	0.6

* Erosion rates at 3 times during the 60-min dry (D) run and near the end of the 30-min wet (W) run and the 15 min runs.
Rain intensities were about 67 mm/hr for D, W, and M; 25 mm/hr for L; 105 mm/hr for H; and 10 mm/hr for VL.

** Not replicated.

Soil loss rates that the USDA Soil Conservation Service considers tolerable to maintain agricultural productivity are less than 12 t/ha annually for these soils. At the medium and high rain intensities, the interrill erosion rates of these soils were greater than 12 t/ha per hour of rainfall, so they are highly erodible and very susceptible to raindrop impact erosion. As discussed previously, crop rows with nearly flat furrow gradients will usually be unable to transport this much sediment and some of it will deposit along the row furrows. However, for conditions where most or all of the sediment can be transported along the furrows and into the streams, the interrill erosion rates measured on these soils show that the sediment loads from upland fields may be very great.

The Loring soil was studied in a bare, tilled condition on land with continuous cotton, permanent pasture, and permanent woodland. All cover was removed, and the soil was cultivated into a seedbed condition. The erodibility of the soil on the woodland plot was less than half that of the plots under continuous cotton. The surface appearance of this woodland cultivated plot after considerable rainfall was still quite rough in comparison to other plots, indicating that the clods and aggregates of this soil condition were much more resistant to breakdown by raindrop impact than those of most other soil conditions. The Loring plot that had been in permanent pasture was considerably less erodible than that in continuous cotton but nearly twice as erodible as the plot that had been in woodland.

The Vicksburg site was cropped to continuous cotton, and tests were made during several crop stages. Before applying simulated rainstorms to some plots, all vegetation was removed and the plots were tilled to a loose, cultivated condition. The highest erosion for this condition occurred in the spring for the bedded cross section with steep row sideslopes and following the first cultivation after the cotton emerged several weeks later. By late October, the erodibility was only about half the erodibility in the spring. These results show evidence that the erodibility of a given soil may vary considerably through the crop season, probably due to physical and chemical changes that affect the soil's susceptibility to erosion by raindrop impact.

The effect of different land use on erosion for several typical conditions (Figure 7) in the Goodwin Creek Watershed is illustrated in Table 4. The erosion rates on part-canopy cotton and part-canopy soybeans

Table 4. Interrill Erosion of Major Cropping Conditions on Typical Watershed Soils

Cover	Soil	Rep.	Loss for run (t/ha)		Erosion Rate* (t/ha-hr)							
			60 min dry	30 min wet	D_{20}	D_{37}	D_{55}	W	L1	M1	H1	VL
Woodland	Loring	I	0.44	0.19	0.51	0.34	0.36	0.38	0.08	0.49	0.79	0.01
leaf, duff	sil	II	0.28	0.09	0.46	0.23	0.19	0.17	0.03	0.18	0.36	0.01
Pasture	Loring	I	0.17	0.06	0.20	0.16	0.14	0.11	0.01	0.09	0.20	-
grasses	sil	II	0.11	0.05	0.17	0.11	0.09	0.08	0.02	0.07	0.13	-
Soybeans	Collins	I	33.6	11.5	41.2	35.5	30.6	26.8	3.1	19.7	50.3	0.4
70% canopy	silt	II	43.0	12.7	55.4	45.1	35.8	30.9	3.3	25.1	64.5	0.6
Cotton	Vicksburg	I	57.9	15.3	77.2	59.7	45.0	33.2	4.1	22.5	73.3	0.3
70% canopy	sil	II**	34.5	12.6	42.2	30.5	24.7	27.6	2.2	18.0	61.6	0.3

* See Footnote for Table 3.

** Plot conditions were not ideal because about 3 weeks between reps.

during mid-summer were quite high, whereas the rates on natural pasture and woodland were almost insignificant. The pasture plots had a thick stand of bermuda grass and the woodland plots had an excellent cover of leaves and duff. Obviously, the interrill erosion rates from good woodland and good pasture are so small that they can probably be neglected in evaluating the total sediment load from watersheds where there also is considerable cropland being used for clean-tilled crop production.

The erosion rates shown in Table 4 with natural pasture and woodland covers can be compared to the results in Table 3 for adjoining plots where this cover was removed and the soil was tilled. Clearly, greatly increased sediment loads may be anticipated when woodland or pastureland is cultivated for intensive cropping. Such erosion rates will not be as great for the first several years as those from land that is continually rowcropped if the soils and topography are similar, but they probably will be about the same thereafter.

The research summarized in Table 5 shows erosion rates at several typical crop stages (Figure 6) for land in continuous cotton. The bedded condition with steep row sideslopes was studied in early spring several weeks after much rainfall. The soil was sealed and there was some evidence of an algal growth on the soil surface due to the wet conditions. The second crop stage studied was shortly after the cotton had emerged and the young cotton had just been cultivated for the first time. The third condition was during mid-summer when the cotton had about a 70% canopy and cotton height was nearly one meter. The fourth condition was with cotton of full canopy where little soil was exposed to direct raindrop impact and cotton height was greater than one meter. The fifth condition was after harvest with the harvested cotton stalks still standing and considerable leaf and boll residue on the surface.

Erosion was very high on this soil for the bedded and early crop growth stages. However, by mid-summer when the soil had settled and canopy covered much of the surface, erosion rates had decreased to about half the spring rate. Much of the erosion from the part-canopy cotton occurred from the large drops that dripped from the leaves along the edge of the cotton row onto the soil surface. By the time the cotton reached full canopy in late summer, interrill erosion rates were only 10 to 20 percent of the rates in the sprng. Direct raindrop impact did not reach the soil surface,

Table 5. Interrill Erosion at Different Stages of Cotton Crop Growth (Vicksburg silt loam)

Crop Stage	Rep.	Loss for run (t/ha)		Erosion Rate* (t/ha-hr)										
		60 min "dry"	30 min "wet"	D_{20}	D_{37}	D_{55}	W	L1	L2	M1	M2	H1	H2	VL
Bedded for planting	I	77.5	33.1	77.0	88.4	87.0	77.8	15.8	18.7	73.7	66.8	146.3	142.7	1.3
	II	55.7	29.9	56.5	70.1	70.8	71.2	12.4	-	52.7	-	199.0	-	1.0
Just after emergence	I	93.9	30.2	129.5	119.7	98.7	71.5	11.6	-	67.8	-	153.8	132.9	0.8
	II	95.8	36.6	117.7	125.8	108.4	80.2	11.5	7.4	74.9	46.6	166.1	136.4	1.0
70% canopy	I	57.9	15.3	77.2	59.7	45.0	33.2	4.1	-	22.5	-	73.3	-	0.3
	II	34.5	12.6	42.2	30.5	24.7	27.6	2.2	-	18.0	-	61.6	-	0.3
Full canopy	I	13.1	4.6	16.9	13.9	11.3	9.8	1.2	-	7.3	-	20.1	-	0.2
	II	14.2	6.1	16.1	16.3	13.6	15.5	1.5	-	9.2	-	25.4	-	0.2
After harv.	I	4.1	2.2	3.9	5.3	5.5	4.9	0.7	-	5.3	-	16.2	-	0.1
	II	4.7	3.5	4.8	5.9	5.9	8.3	0.7	-	7.3	-	21.7	-	0.1

* See Footnote for Table 3.

but drips from the cotton leaves onto the bare soil beneath did cause some erosion. After harvest in the autumn, the plot surface was well settled and covered by considerable crop residue. Raindrops were not intercepted by a significant amount of canopy cover, but the residue cover on the soil surface plus the decreased erodibility of the soil itself, as indicated by the results in Table 3, resulted in interrill erosion rates that were considerably less than 10 percent of the rates in early spring.

The results in Table 5 show that the potential for sediment production from row sideslopes decreases greatly through the cotton crop year from the bare, bedded condition and early weeks of crop growth in the spring until the post-harvest condition with all natural crop residues remaining. Based on these results, the potential for interrill erosion is greatest from the time that post-harvest crop residues are turned under by land cultivation until the growing cotton provides a significant canopy. This period coincides with much of the intense rainfall that occurs in Mississippi.

The results in Table 6 compare the latter 3 crop stages in Table 5 with adjoining plots where all of the crop canopy and surface residue cover was removed but no tillage was performed (Figure 8). These results indicate the effect of vegetative cover alone on the resulting interrill erosion. The effect of part canopy as compared to no canopy in mid-summer shows that the part canopy did not greatly reduce erosion during the early storms but did decrease it considerably after an appreciable amount of rainfall had occurred. In late summer, the plots without full canopy had about twice as much erosion as the plots with full canopy, and again the difference increased as the amount of rainfall continued. In the fall, erosion rates with the vegetative cover as compared to those without cover are even more different than at the other stages. However, note that evidence of decreased erosion through the crop year occurred on these bare, untilled plots, just as it did for the bare, tilled plots in Table 3 These results show that crop canopy is an important factor in decreasing erosion, but that the reduced erodibility of soil throughout the crop year is another important characteristic. This latter characteristic has not been generally recognized. Figure 9 shows this change through the cotton crop year with the crop cover, without the cover, and bare-tilled.

Extensive analyses of the erosion rates during the 15-minute storms on the conditions in Tables 3, 4, 5, and 6 plus those for many other soils

Table 6. Canopy and surface cover effects on interrill erosion for different stages of cotton (Vicksburg silt loam)

Crop Stage	Crop Cover**	Rep.	Loss for Run (t/ha) 60 min "dry"	30 min "wet"	Erosion Rate* (t/ha-hr) D_{20}	D_{37}	D_{55}	W	L1	M1	H1	VL
70% canopy	Covered	I	57.9	15.3	77.2	59.7	45.0	33.2	4.1	22.5	73.3	0.3
		II	34.5	12.6	42.2	30.5	24.7	27.6	2.2	18.0	61.6	0.3
	No Cover	I	50.9	17.3	63.3	64.9	52.0	38.9	5.6	29.8	96.8	0.5
		II	37.5	15.0	44.2	45.2	41.5	34.0	4.5	30.6	88.7	0.8
		III	66.2	19.0	86.2	67.2	63.0	40.6	3.8	31.4	86.4	0.6
Full canopy	Covered	I	13.1	4.6	16.9	13.9	11.3	9.8	1.2	7.3	20.1	0.2
		II	14.2	6.1	16.1	16.3	13.6	13.5	1.5	9.2	25.4	0.2
	No Cover	I	45.6	16.1	52.2	46.0	44.3	35.5	4.8	30.8	85.3	0.7
		II	22.1	11.0	21.1	26.3	27.0	24.6	3.3	22.9	60.6	0.7
Harvest Residue	Covered	I	4.1	2.2	3.9	5.3	5.5	4.9	0.7	5.3	16.2	0.1
		II	4.7	3.5	4.8	5.9	5.9	8.3	0.7	7.3	21.7	0.1
	No Cover	I	19.4	9.1	20.2	24.7	23.9	21.5	3.2	18.7	57.1	0.5
		II	17.7	9.5	15.5	23.9	23.4	21.4	2.2	20.8	55.4	0.4

* See Footnote for Table 3

** Covered denotes canopy and/or residue cover typical of field at time of test. No Cover denotes bare, undisturbed soil with canopy and residue removed.

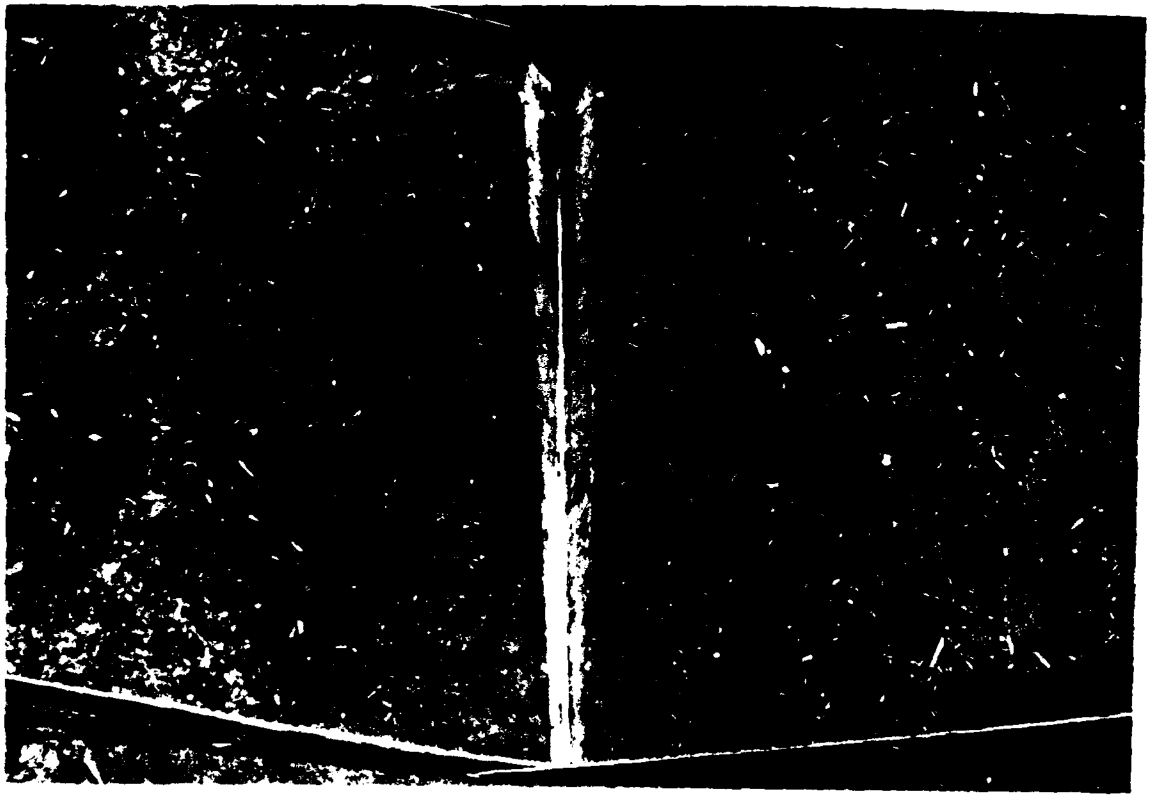


Figure 8 Typical plot with cotton canopy and surface residues removed, but not tilled.

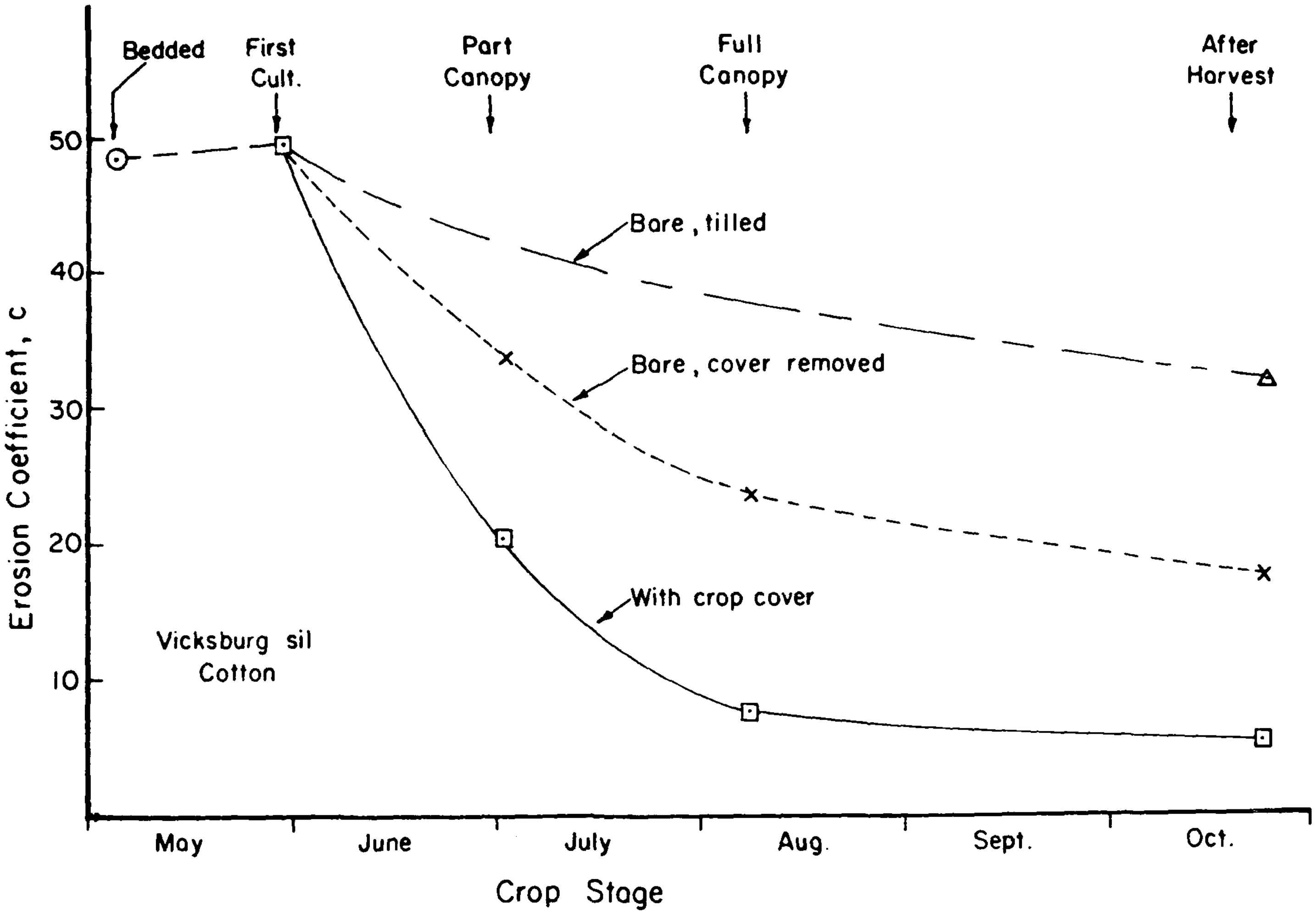


Figure 9 Change in erosion through the cotton crop year for different cover and soil conditions as characterized by the erosion coefficient, c, in $E = cI^2$.

from other parts of Mississippi a[illegible] in Iowa have shown that interrill erosion varies as an exponential power of rainfall intensity (Meyer, 1980). These analyses have also shown that erosion from soils of low clay contents is very closely proportional to the square of the intensity for a wide range of cropping and cover conditions, including those that were studied during this research (Figure 10). Therefore, the erosion rates for the 15-minute runs at different intensities that followed the 60- and 30-minute storms, to standardize the moisture conditions, were fitted using the equation $E = cI^2$ where E is the rate of erosion in tons per hectare per hour, I is the rainfall intensity in millimeters per minute, and c is the coefficient of best fit. Using this relationship, the value for c indicates the relative erosion rates for the different soils and cropping conditions and thus provides a means of comparing the various conditions. For the bare, tilled soils in Table 3, it may be considered an index of interrill erodibility for the different soils. Values of this coefficient c for the data in Tables 3, 4, 5, and 6 are shown in Table 7. These values summarize the results from these other tables for storms following the initial 60- and 30-minute rainstorms.

The data in Table 3, 4 and 5 show that the erosion rate decreased with additional rainfall at the common intensity of about 67 mm/hr, once the soil was thoroughly wetted. This decrease was attributed to prior erosion of detached material and decreased rate of detachment of remaining soil. The trends of decreased erosion with prior rain at 67 mm/hr are illustrated in Figure 11 for different soils, in Figure 12 for different prior crops on Loring soil, in Figure 13 for different crop stages, and in Figure 14 for different covers on typical Watershed soils.

3.2 SEDIMENT SIZES

As shown by the research discussed in the previous section, much sediment may be eroded during intense rainstorms from row sideslopes of land in rowcrop production and other interrill areas. The transportability of such sediment by runoff and its potential for subsequent deposition depend largely on its size distribution.

Sediment from cohesive soils is composed of both aggregates and individual primary particles. The extent of aggregation and the sizes of those aggregates that remain stable during erosion may vary from soil to soil. Thus, the size distribution of sediment in the feld may be quite

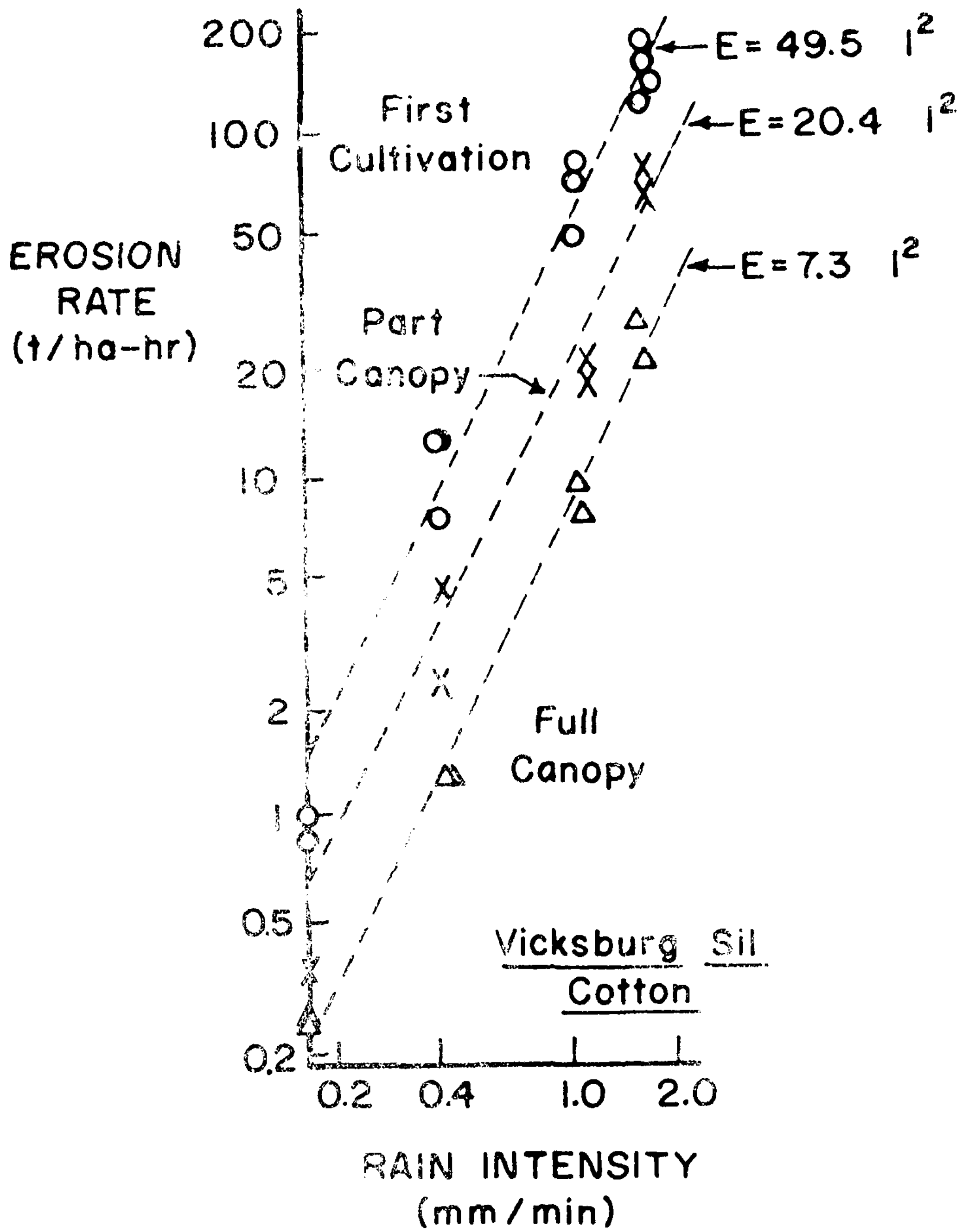


Figure 10 Effect of rainfall intensity on row sideslope erosion rates at several stages of crop growth.

Table 7. Erosion Coefficient, c, in the Equation $E=cI^2$ for Different Soils, Crop, and Cover Conditions

Bare, tilled Soils	Date	Prior Crop	c
Arkabutla sil	6/78	Cotton	30.6
Collins silt*	8/79	Soybeans	22.1
Grenada sil	7/78	Cotton	39.0
Loring sil	5/79	Cotton	17.4
Loring sil*	8/79	Pasture	12.1
Loring sil*	8/79	Woods	8.5
Memphis sil	8/78	Cotton	28.9
Ocklockonee sil	6/79	Cotton	23.1
Vicksburg sil	6/78	Cotton	49.5
Soil Cover	**Date**	**Soil**	**c**
Pasture	8/79	Loring sil	0.05
Woods	8/79	Loring sil	0.19
Soybeans	8/79	Collins silt	16.0
Cotton	7/78	Vicksburg sil	20.4
Cotton Stages	**Date**	**Soil**	**c**
Bedded to plant	5/79	Vicksburg sil	48.6
Emerging	6/78	Vicksburg sil	49.5
Part Canopy	7/78	Vicksburg sil	20.4
Full Canopy	8/78	Vicksburg sil	7.3
After Harvest	10/78	Vicksburg sil	5.8
Cover Effect	**Date**	**Soil**	**c**
Part Canopy	7/78	Vicksburg sil	20.4
Cover Removed	7/78	Vicksburg sil	28.3
Full Canopy	8/78	Vicksburg sil	7.3
Cover Removed	8/78	Vicksburg sil	23.4
Harvest Residues	10/78	Vicksburg sil	5.8
Residues Removed	10/78	Vicksburg sil	17.7

* Plots were not replicated.

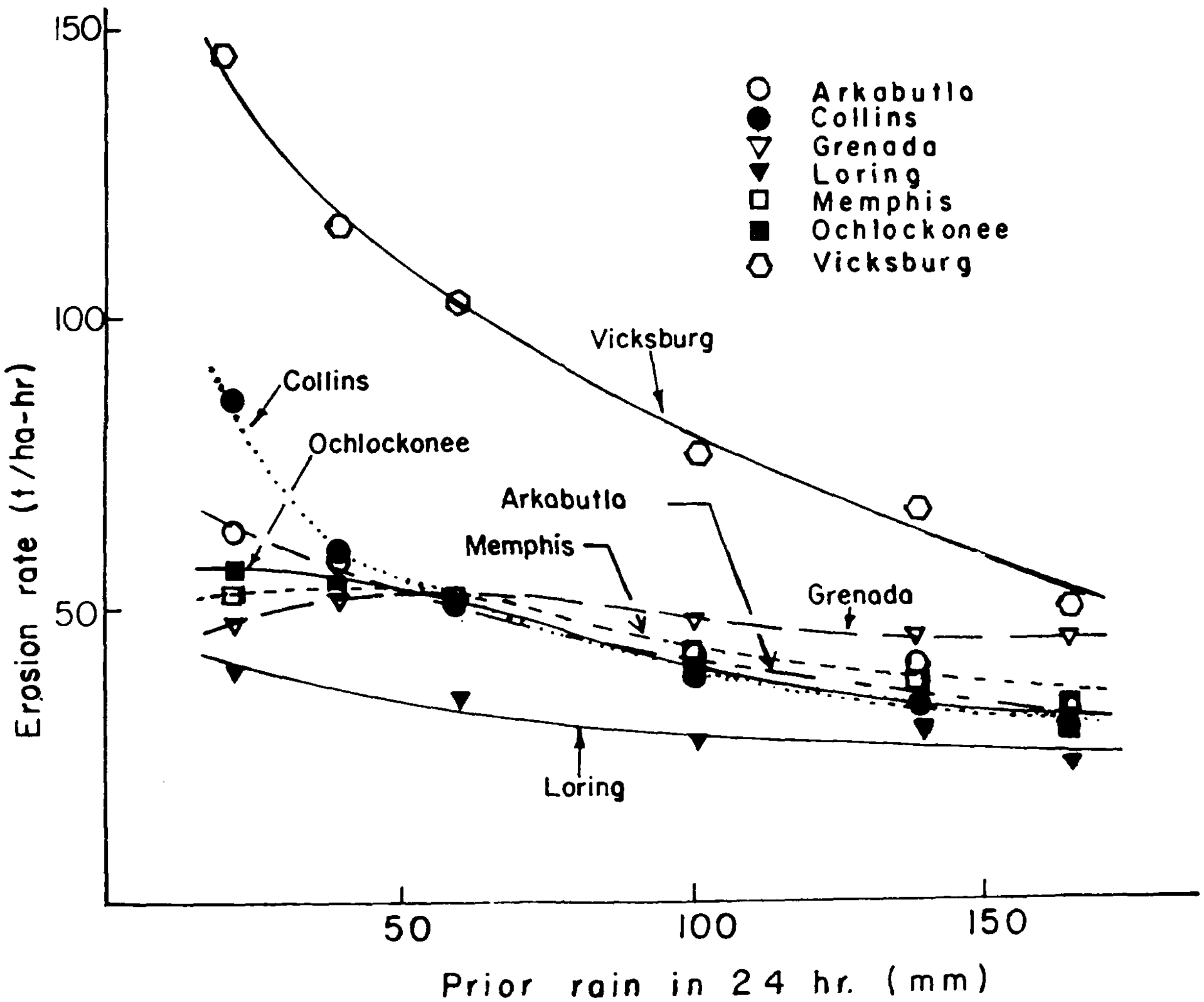


Figure 11 Change in erosion rate due to additional rainfall for various bare, tilled soils.

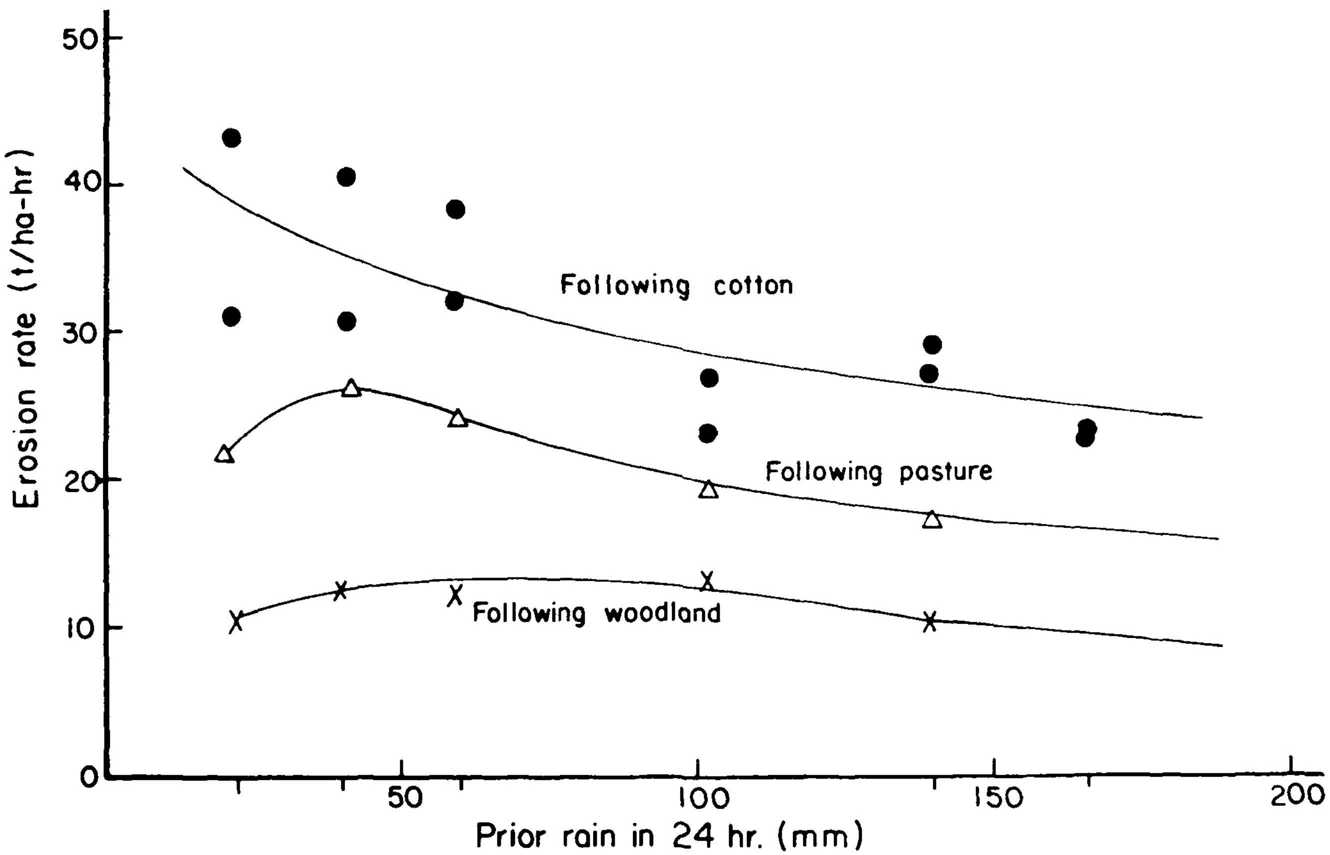


Figure 12 Change in erosion rate due to additional rainfall on bare, tilled Loring silt loam following different prior crops.

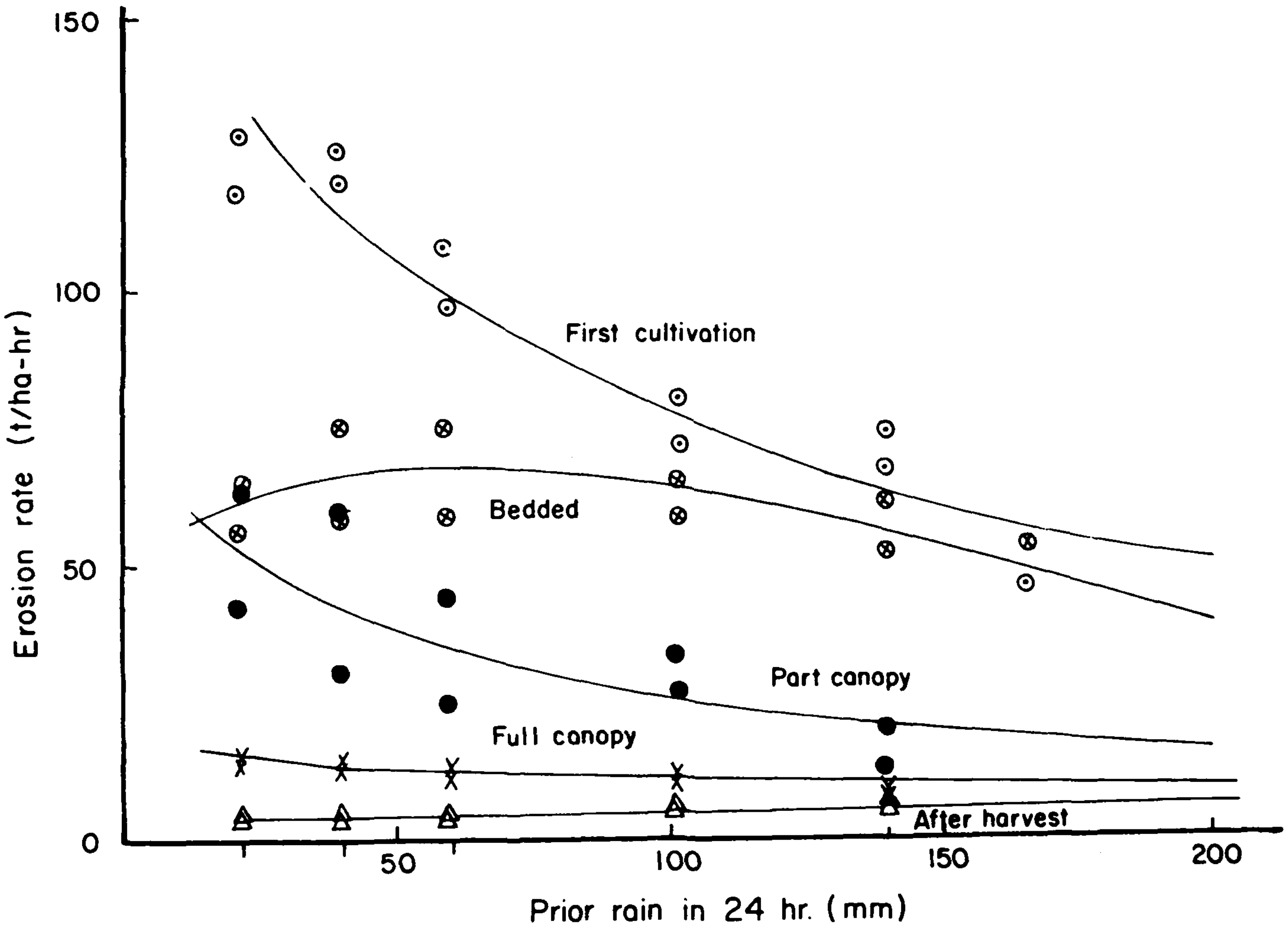


Figure 13 Change in erosion rate due to additional rainfall for several major stages of cotton.

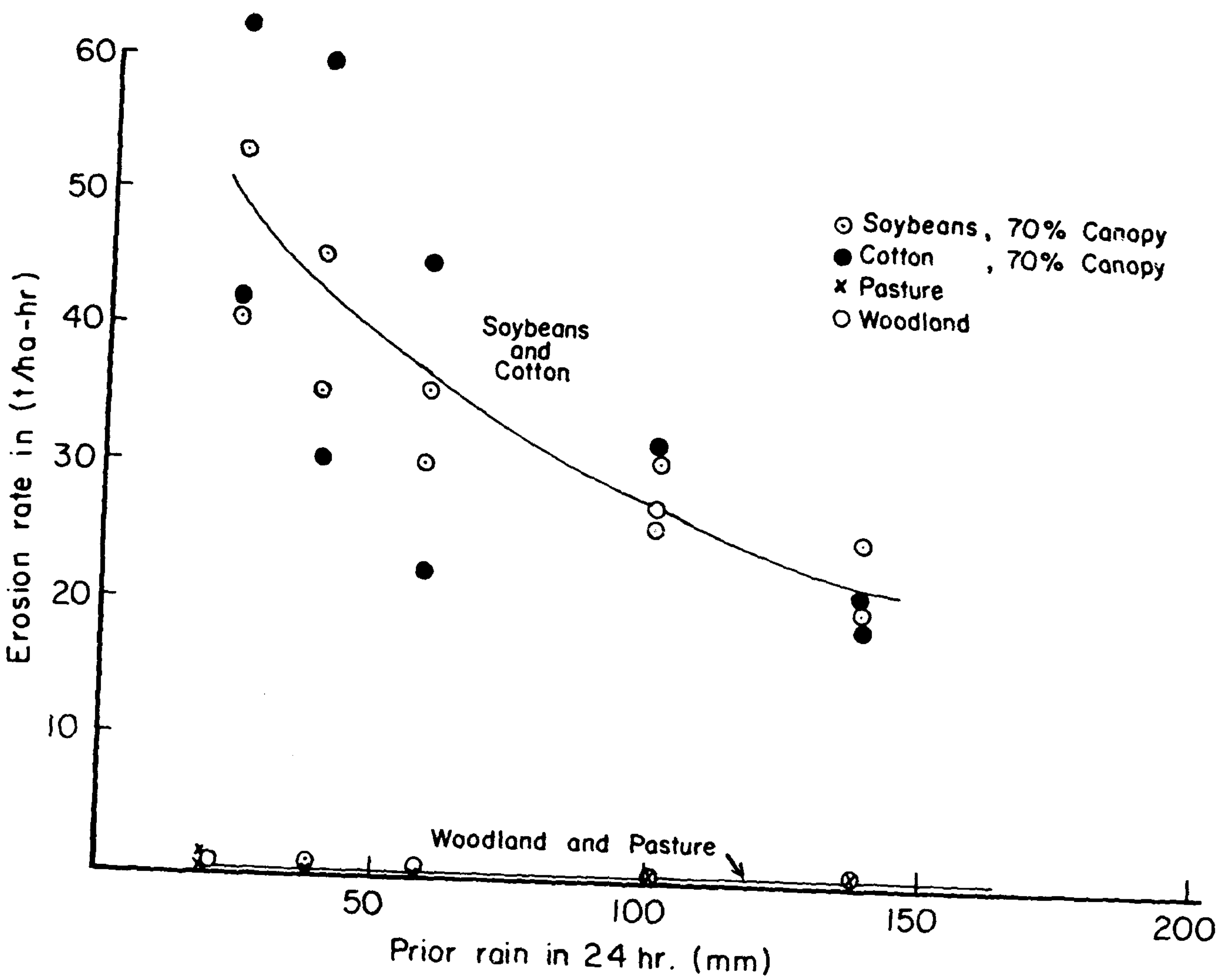


Figure 14 Change in erosion rate due to additional rainfall for several major watershed cropping conditions.

different from the size distribution of the dispersed original soil. If the transportability of sediment is inferred from dispersed textural characteristics rather than the actual sediment sizes, large errors may result. Although wet aggregates are somewhat less dense than primary particles of the same size, such aggregates usually are much larger than most of the primary particles of which they are composed and thus are much less easily transported.

To learn more about the size distribution of sediment in the form that it is eroded, some of the runoff samples that were taken periodically during soil erosion research on crop row sideslopes were analyzed for the size distributions of the undispersed sediment. A sample of the original surface soil also was dispersed to determine textural size distribution. This paper reports various soil and sediment size comparisons for different soils under several conditions.

3.2.1 Background

Soil aggregation has been of both practical and scientific interest for many years because it is so closely related to soil structure, soil tilth, soil moisture characteristics, and other important soil properties. Methods have been devised for measuring soil aggregation and aggregate stability (Yoder, 1936; Kemper and Chepil, 1965), but they were designed primarily to evaluate soil structure. More recently, a few studies of the sizes of sediment resulting from erosion have been conducted (Weakly, 1962; Swanson et al., 1965; Swanson and Dedrick, 1967; Meyer et al., 1975a; Laflen et al., 1978, Barnett et al., 1978; Gabriels and Moldenhauer, 1978). These studies plus numerous field observations have shown that much sediment erodes as aggregates. However, sediment sizes are commonly evaluated after the sediment is fully dispersed into its primary particles (Doty and Carter, 1965; Young and Mutchler, 1969; Meyer et al., 1975b; Young and Onstad, 1976). The dispersed sediment-size distribution is an indicator of fine-particle enrichment, surface area, and chemicals transported with the sediment, but it is not appropriate for determining the transportability of the sediment during runoff.

Very few data are available on the size distribution of sediment in the form that it is eroded. The research reported in this paper and efforts by other researchers are beginning to provide some of these data. Such data are needed in recently proposed methods for improving predictions

of sediment yields from farm fields, terrace systems, and watersheds. In particular, the USDA-SEA-AR effort to evaluate nonpoint source pollution incorporates the sediment size distribution in the erosion/sedimentation model (Foster et al., 1980). Sediment size characteristics are considered in evaluating sediment yield and in determining the chemical transport capabilities of this sediment. Sediment size information is also needed for other purposes such as better estimates of sediment transport, sediment delivery, and sediment deposition, both on land areas and in bodies of water. This research provided data on sediment size distributions resulting from interrill erosion for various soils and soil conditions.

3.2.2 Procedure

Field analyses of size distributions of eroded sediment were made for each of the seven different soils and each condition described earlier. Samples for sediment size analysis were collected after 30 and 50 minutes during the dry run, after 20 minutes during the wet run, and after 10 minutes during the 15-minute runs.

The samples were immediately wet-sieved through a nest of sieves with 1000, 500, 250, 125, and 63 μm openings to determine the content of sand-sized sediment. (The 63μm sieve was the smallest that would satisfactorily pass sediment during wet sieving.) Wet sieving consisted of gentle, thorough sieve-by-sieve washing of the sediment, using ample clean water to flood each sieve. The material passing through the 63 μm sieve was then transferred to a 3-liter cylinder, and pipette withdrawals (Guy, 1969) were taken to evaluate sediment at sizes of 31, 16, 8, and 4 μm. (These withdrawals could all be made within 1 h after mixing, but the wait for 2 μm withdrawals would have been too long for field studies.) All such size-distribution tests were conducted in a controlled-temperature mobile-trailer laboratory near the research plots (Figure 15). The sieve and pipette specimens were subsequently taken to the Sedimentation Laboratory for drying and weighing, and the resulting data were used to compute the sediment-size distributions.

In considering the resulting sediment size distributions, the difference in techniques for evaluating sediment sizes larger and smaller than 63 μm must be recognized. Sizes larger than 63 μm were evaluated by sieving, whereas smaller sizes were evaluated from pipette withdrawals. Both are standard methods for sizing dispersed particles, but sieving

Figure 15 Laboratory trailer where various field analyses including sediment size evaluations were made.

evaluates by particle cross section, whereas pipetting is based on particle fall velocity. For aggregated sediment, the sizes evaluated by sieve are comparable in cross section although their densities may be different. In contrast, sizes evaluated by pipette have comparable fall velocities, but the cross sections of any aggregates will be larger than primary particles because they are less dense. Therefore, sediment sizes smaller than 63 µm were evaluated in terms of their fall diameters, i.e. diameters of spheres having densities of 2.65 that fall at the same velocities as irregular particles of unknown densities.

A sample of the top 25 mm of surface soil from near each plot was collected at the time of the erosion studies. The primary particle size distribution of this soil after dispersing was determined, using the techniques used to evaluate the sediment-size distributions in the field.

Except as indicated, duplicate plots were studied for each condition and several sediment-size samples from each plot were averaged to obtain the sediment size distributions presented.

To compare the sediment characteristics of the different soils in a common condition, only samples from bare, freshly tilled plots with a prior use history of continuous row cropping were used. To compare sediment characteristics at different crop stages during the year, the Vicksburg soil was tested five times through the cotton crop year. To compare the effect of different prior land uses, sediment sizes from a Loring soil were evaluated after tillage of land with past histories of continuous cotton, continuous pasture, and continuous woodland. These soils and cropping practices are representative of most of the conditions found in the Goodwin Creek Watershed.

3.2.3 Results and Discussion

The size distributions of the sediment eroded from the row sideslopes of the bare, tilled soils are shown in Fig. 16 and the second columns for each soil in Table 8. These soils produced a considerable range of sediment size distributions, although several were very similar. The Collins and Vicksburg soils had essentially the same sediment size distribution. The Loring soil produced more fine sediment less than 31 µm than any of the other soils, but above 31 µm the size distribution was very similar to that of the Collins and Vicksburg soils. The Grenada, Arkabutla, and Memphis soils produced very similar sediment sizes with more

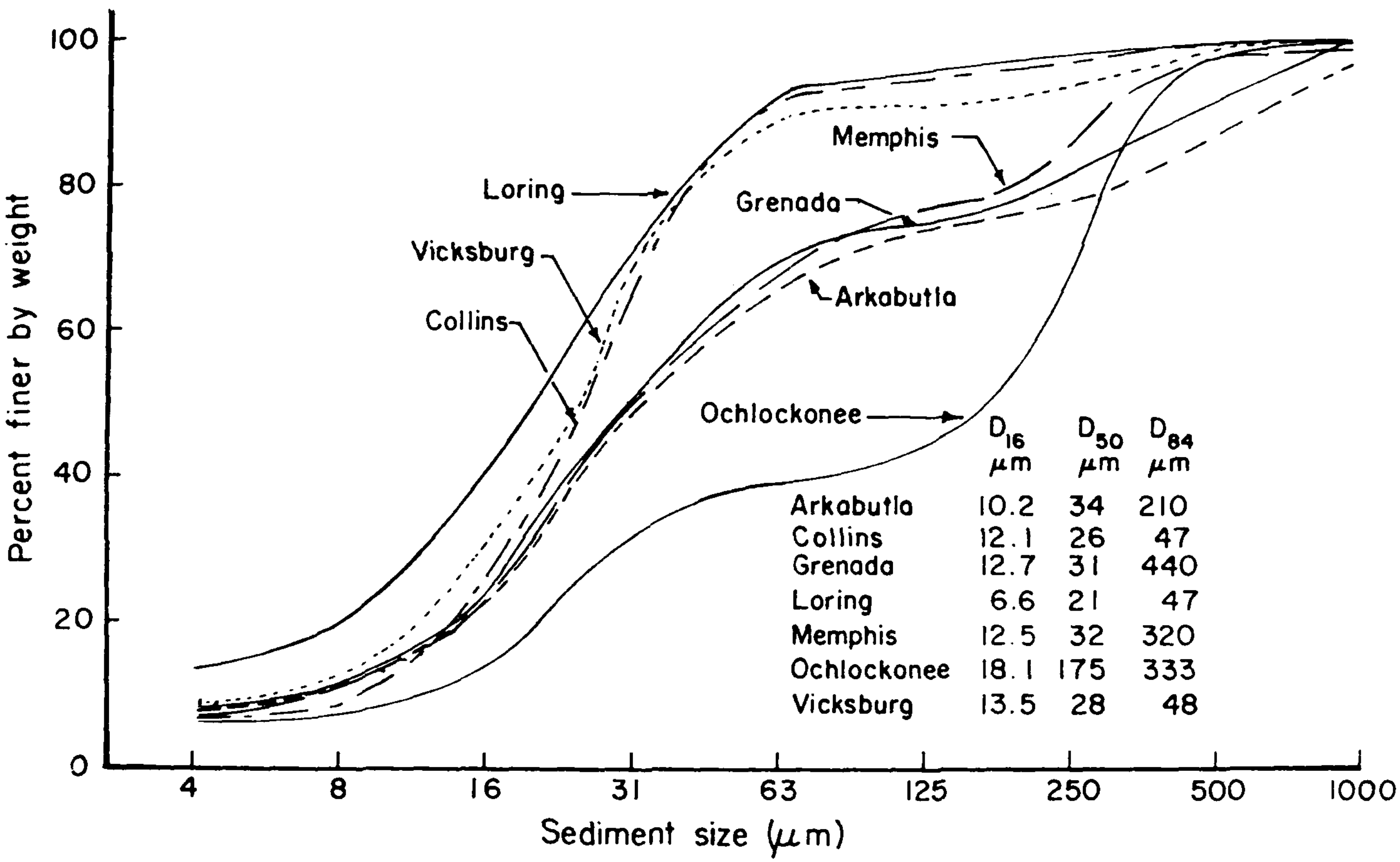


Figure 16 Sediment size distributions for the seven Watershed soils.

Table 8. Size Distributions of Dispersed Surface Soil and Eroded Sediment for Soils Typical of Those Within the Goodwin Creek Watershed (percent by weight).

Size Class	Arkabutla sil		Collins silt		Grenada sil		Loring sil	
μm	Disp. Soil	Eroded Sediment	Disp. Soil	Eroded Sediment	Disp. Soil	Eroded Sediment	Disp. Soil	Eroded Sediment
> 1000	0.3	0.7	0.1	0.3	0.1	5.0	T	0.2
500 - 1000	1.4	2.9	0.2	1.0	0.6	8.8	0.1	0.9
250 - 500	4.0	8.9	0.3	2.2	2.0	10.1	0.5	2.5
125 - 250	10.0	13.7	0.5	2.8	2.6	5.8	0.5	2.7
63 - 125	8.3	9.0	0.5	1.8	1.3	5.0	0.4	1.7
31 - 63	12.7	17.5	22.1	27.1	21.8	15.3	21.6	21.5
16 - 31	22.6	21.5	45.5	40.7	40.3	27.7	36.5	32.8
8 - 16	14.7	13.6	21.4	16.2	13.5	12.4	16.8	19.5
4 - 8	6.7	5.5	4.3	1.0	3.1	3.7	6.0	5.1
< 4	18.9	6.7	6.5	6.9	14.7	6.2	17.6	13.1

Size Class	Memphis sil		Ochlockonee sl		Vicksburg sil	
μm	Disp. Soil	Eroded Sediment	Disp. Soil	Eroded Sediment	Disp. Soil	Eroded Sediment
> 1000	T	0.7	0.2	0.2	0.2	0.1
500 - 1000	0.1	6.4	2.2	2.1	0.5	0.5
250 - 500	0.2	13.0	20.4	30.6	1.7	2.9
125 - 250	0.3	6.9	25.5	24.3	2.7	4.1
63 - 125	0.4	3.0	6.7	4.4	1.3	2.8
31 - 63	18.6	20.8	12.2	7.8	19.4	22.4
16 - 31	34.3	28.1	18.8	16.9	45.1	43.5
8 - 16	14.1	10.6	7.8	6.2	15.6	15.9
4 - 8	5.4	3.7	1.3	1.1	3.9	3.2
< 4	26.6	6.8	4.9	6.4	9.6	4.6

Each dispersed soil size distribution is based on triplicated analyses, and each sediment size distribution is the average of 4 to 6 runoff samples taken at a rain intensity of about 67 mm/h.

sand-sized sediment than the Loring, Collins, and Vicksburg soils. The sediment from the Ochlockonee sandy loam soil was much coarser than the silt loam soils.

Comparison of the size distributions of the dispersed surface soil taken adjacent to the study plots to those of the eroded sediment for the various soils in Table 8 shows that more of the Grenada and Memphis sediments erode as aggregates. Arkabutla, Loring, Vicksburg, and Collins soils have only small amounts of aggregated sediment while the Ochlockonee sediment size distribution differs only slightly from that of the dispersed soil.

Fig. 16 also shows the D_{16}, D_{50}, and D_{84} values. D_{16} indicates the diameter at which 16% of the sediment is finer, D_{50} the diameter at which 50% is finer , and D_{84} the diameter at which 84% is finer. Except for the Loring soil which has more fine material and Ochlocknee soil which is a coarse sandy loam, all the sediment D_{16} values ranged between 10 and 14 μm and the D_{50} values between 26 and 34 μm. Since the D_{16} and D_{50} values for the dispersed soil would be much smaller than the D_{16} and D_{50} values for the corresponding sediment, aggregation is evident. However, the aggregate sizes can be best understood by observing the D_{84} values since 16% of the sediment is composed of particles larger than the D_{84} value shown. Except for the Ochlockonee soil, all soils have a dispersed D_{84} value less than 125 μm, yet three of them have sediment with a D_{84} value exceeding 200. Thus, many of the larger sediment particles were aggregates.

The eroded sediment from the Grenada soil shows the coarsest aggregation with a D_{84} value of 440 (16% of material > than 440 μm) while only 6.6% of the dispersed soil exceeds 63 μm. This soil, therefore, erodes as though it were composed of much coarser particles. Memphis and Arkabutla sediments are the next most aggregated with D_{84} values of 320 and 210 respectively. The Loring, Collins, and Vicksburg produce only slightly aggregated sediments with only 16% exceeding 48 μm. The Ochlockonee sediment is less aggregated than the others but the primary particles are large.

The sediment from watershed soils was largely silt and fine sand sized. Much of the sediment was in the form of primary soil particles because most of the soils were only slightly aggregated, although several were moderately aggregated. Soils that are more cohesive than these of the

watershed and contain large amounts of clay are often highly aggregated and have more large sediment that moves as stable aggregates (Meyer et al., 1980). Generally, sediment from the Watershed soils was predominantly silt-sized. Silt-sized sediment is readily transported through the surface drainage system.

Table 9 shows the effect of prior land use on the size distribution of sediment eroded from freshly tilled Loring silt loam. For this study, the soil of the tilled treatment was prepared as nearly the same as possible at each location. The existing cover was removed and the plots were tilled to a depth of 50 to 75 mm. Comparison of the three conditions shows that the sediment size distribution was affected by land use history. The land with continuous cotton history produced the least percentage of large aggregates in the sediment, the land tilled from permanent pasture which had not been row-cropped for many years produced more large sediment than the continually cultivated land, but less than the tilled woodland with no known history of cultivation. This suggests that continuous cultivation appreciably reduces the amount of aggregation as compared to less intensive land uses.

Table 10 shows the relationship of sediment size distribution to stages of the cropping season. For the poorly aggregated soil studied, there was very little change in the sediment size distribution with canopy cover or with time of year during the cropping season. This suggests that the size distribution of eroded sediment is a fairly distinct characteristic of a given soil in a given condition.

3.3 TRANSPORT OF ERODED SEDIMENT

The amount of sediment that is transported along row furrows, rills, and other concentrations of runoff determines the sediment delivered to some downstream point such as a stream channel or reservoir. The rate of sediment transport for such conditions depends on the rate at which the sediment is eroded from interrill areas to the concentrated flow, the size distribution of that sediment, and the characteristics of the flow channel. A laboratory study was conducted to evaluate the capability of runoff to transport sediment along crop row furrows and other runoff channels where flow concentrates. Such information may be used to route the sediment through runoff flow systems, using the erosion rates and sediment size distributions discussed in the previous two sections.

Table 9. Sediment Size Distributions for Different Prior Use Conditions on Bare, Tilled Loring silt loam as Compared to Dispersed Soil Size Distributions at Each Location (percent by weight)

	Prior Use					
	Cotton		Pasture*		Woodland*	
Size Class	Dispersed Soil	Eroded Sediment	Dispersed Soil	Eroded Sediment	Dispersed Soil	Eroded Sediment
> 1000	0.1	0.2	0.2	0.8	0.1	4.5
500 - 1000	0.5	0.9	0.3	3.3	1.0	9.1
250 - 500	1.1	2.5	0.9	6.6	1.4	8.2
125 - 250	0.8	2.7	0.7	6.8	1.1	6.2
63 - 125	0.4	1.7	0.6	3.6	1.0	2.6
31 - 63	17.8	21.5	21.2	33.2	22.1	12.6
16 - 31	39.2	32.8	36.6	23.0	35.7	28.1
8 - 16	16.6	19.5	16.8	8.3	19.0	15.6
4 - 8	5.6	5.1	5.0	2.4	6.2	3.6
< 4	17.9	13.1	17.7	12.0	12.3	9.5

* 1 plot only

Table 10. Sediment Size Distributions at Progressive Stages of Cropping Year for Cotton on Vicksburg silt loam soil (percent by weight)

	Crop Stage				
Size Class	Bedded before Planting	At Emergence	70% Canopy	Full Canopy	After Harvest
> 1000	0.7	0.3	0.5	0.4	0.6
500 - 1000	0.5	0.7	2.8	1.7	1.1
250 - 500	2.6	4.0	5.2	8.0	3.7
125 - 250	3.7	5.6	6.4	9.4	4.3
63 - 125	1.4	2.7	2.9	4.1	3.1
31 - 63	20.4	21.8	23.9	24.2	21.4
16 - 31	44.5	40.0	39.1	33.9	42.4
8 - 16	16.0	15.2	13.2	12.1	14.2
4 - 8	1.7	3.8	0.9	0.8	1.5
< 4	8.5	5.9	5.1	5.4	8.5

3.3.1 Background

The initiation of particle movement by concentrated flow results from the interaction between fluid elements within an eddy and the sediment grains (Sutherland, 1967). This interaction may be described as the initiation of sediment motion and the suspension of grains by the flow.

Particle movement is initiated in a channel when the drag of the moving fluid overcomes gravitational and cohesive forces on the particle. The detached particle thus rolls along with the fluid, or, if the turbulent velocity providing the particle lift force is greater than the particle settling velocity, the particle is swept upward into suspension (White, 1940; Kalinske, 1947; Coleman, 1967). Once motion is initiated, the subsequent behavior of the particles is largely a function of their settling velocity.

For cohesive material, the resistance to incipient motion depends on the strength of the cohesive bonds between the particles. When the cohesive bonds are overcome by the tractive force, the individual particles become a part of the noncohesive group. Scour or transport and deposition become a function of the properties of these separate particles. Fortier and Scoby (1926) discussed incipient motion of nonscouring channel velocities. Grissinger (1966) studied the properties of certain clay systems that are conducive to erosion resistance and evaluated the stability of cohesive materials.

There are 3 modes of sediment transport:

1. Traction transport occurs when particles roll, slide, or tumble along the channel bottom. The traction transport of particles is related to a shearing force along the channel bottom, which is caused by flow. Traction is also related to particle shape, size, and settling velocity.

2. Saltation movement may be considered an intermediate phase between traction and suspension transport. Saltation begins when a particle is lifted upward and has a small forward velocity. During this jump, the particle's forward velocity increases until the supplied energy for this lift diminishes and the gravitational force overtakes the lift force. The particle then moves downward.

3. Suspension transport occurs when the turbulent intensity of the fluid is greater than the settling velocity of the particles which are in motion due to lift and drag forces. Size and shape of the particles are

related to this type of motion. The concentration of suspended particles is much greater near the channel bed than near the water surface.

Although transport of sediment in streams and channels has been extensively investigated, very little study of sediment transport has been conducted for conditions that are typical of upland runoff in rills and furrows. Such conditions generally are characterized by flow depths of less than several centimeters, flow rates of less than 0.001 m^3/sec, channel steepnesses up to several percent, and the presence of impacting raindrops on the flow. This research was designed to study sediment transport for such conditions.

3.3.2 Procedure

A 2-meter long channel with a cross section that is typical of furrows between cotton rows was constructed. The surface of this channel was covered with sediment of the size being studied. The furrow channel was studied at steepnesses of 0.2, 1.0, 2.5, and 5.0 percent. To simulate runoff from a much longer furrow above the test section, water was added at the upper end of the channel at rates of 26.2, 39.4, 52.3, and 65.6 kg/min to represent runoff from furrow lengths of 31, 46, 62 and 77 meters at a runoff rate of 50 millimeters per hour. Sediment was introduced into the inflow from a commercial vibrating-feed system. Sediment sizes studied averaged 77, 151, 302, and 603 μm. Sediment transport capacity measurements at all combinations of the above conditions were made without rainfall and in the presence of intense rain. Outflow from the channel was collected to evaluate the actual runoff rate and the maximum rate of sediment transport that the different flow conditions were capable of maintaining.

To conduct a run, the selected particles were glued to the channel surface and the feed system was filled with the same sized particles. The bed was adjusted to one of the slope steepnesses by means of a threaded jack. The selected inflow rate was begun. The rate of sand that was added to the inflow was varied until there was no evidence of a net change in the sand formations on the bed. When the channel was in dynamic equilibrium, where the amount of sand along the channel was not noticeably increasing or decreasing with time, the runoff and erosion rate were evaluated at least in triplicate.

3.3.3 Results and Discussion

Data were obtained from 156 runs. Three replications of all treatment combinations were studied. Two types of sediment motion were observed: the dune type of motion and the ribbon motion, which was actually a strip of sediment flowing through the channel. These two types of motion were more observable when slope was changed and the other two variables were held constant. The transition from dune to ribbon motion came between slope steepnesses of 1 and 2½ percent. This phenomenon can be related to discharge, depth, slope, Froude Number, and Reynolds Number (Willis, et al., 1972). This is also related to particle size, settling velocity, and shear velocity (Inman, 1944).

The results from this study are summarized in Table 11. Complete data were presented by Zudhi (1979).

As shown in Table 11, the steepness of the furrow slope had a tremendous effect on the capacity of the furrow to transport this sandsized sediment. The amount of sediment transported per unit of time for a furrow steepness of 1 percent was generally 50 to 100 times the amount that could be transported at 0.2 percent. The amount transported at 2.5 percent was generally 500 to 1000 times that at 0.2%, and the transport at 5% furrow slope was generally more than a 1000 times that at 0.2%. Furrow steepnesses of 0.2% are seldom found on upland fields, although they are a common steepness on land that is formed for drainage in the Mississippi Delta. Furrow slopes of 1% are much flatter than most furrows on upland fields except on slopes that are contoured or on bottomland fields along streams. Furrow steepnesses of several percent and greater are common on sloping land that is not contour farmed or terraced.

Increased furrow length, as simulated by increased flow rates, also affected the rate of sediment transport greatly. The amount of sediment transported per unit of time generally increased more than the relative increase in amount of flow. The results indicate that doubling furrow length will more than double the capacity of the furrow to transport sediment at the lower end. The maximum flow studied during this research was equivalent to that for furrows less than 100 meters long, yet furrow lengths of several hundred meters often occur on flatter fields.

Sediment size also affected the sediment transport capacity. Considerably more very fine sand could be transported for a given flow

Table 11. Transport capacities (gm/min) along row-furrow channels for four flow rates, four slope steepnesses, and four particle diameter groups with and without rainfall

Slope %	Flow Rate L/min	Sand size group: D = 63-88 μm Rain		D = 125-177 μm Rain		D = 250-354 μm Rain		D = 500-707 μm Rain	
		Rain	No Rain	Rain	No Rain	Rain	No Rain	Rain	No Rain
0.2	26.2	2.1	0.8	0.44	0.2	0.53	0.2	0.1	0.1
0.2	39.4	2.5	1.3	0.59	1.1	0.68	0.5	0.4	1.0
0.2	52.3	4.0	1.8	1.95	1.6	0.82	1.1	0.5	2.2
0.2	65.6	7.3	5.5	2.06	2.9	1.12	1.2	1.0	3.4
1.0	26.2	25.4	14.1	22.6	18.0	24.3	37.0	22.6	36.8
1.0	39.4	75.6	92.6	61.6	49.4	50.5	61.2	43.4	65.2
1.0	52.3	244.9	178.8	113.9	112.8	82.8	102.7	58.3	94.3
1.0	65.6	213.6	289.9	203.0	184.8	115.0	135.8	85.1	116.4
2.5	26.2	1125.9	825.7	425.4	346.6	263.8	226.8	196.8	218.0
2.5	39.4	1598.5	1898.5	998.1	958.5	332.4	378.9	334.6	392.7
2.5	52.3	2740.0	2662.8	1349.9	1104.6	491.3	529.1	455.5	459.1
2.5	65.6	3569.0	4220.4	1897.0	1309.9	634.2	643.7	550.9	579.6
5.0	26.2	2313.0	1942.2	1795.1	1651.6	966.9	722.2	658.5	754.2
5.0	39.4	2554.6	2539.2	2602.0	2202.0	1092.2	1003.5	1102.6	1150.0
5.0	52.3	6964.0	6832.8	4086.7	3358.4	1497.5	1042.3	1262.4	1548.9
5.0	65.6	6562.0	8634.0	4820.8	4410.6	2058.0	1981.3	1405.8	2037.0

condition than coarser sand sizes. Further research has not yet been possible to evaluate the transport of finer silt-sized sediment. However, the effect of sediment size on transport capacity found during this research indicates that more silt-sized sediment per unit of flow for a given flow condition would be transported than the sand-sized sediment that was studied. Most of the soils in the Goodwin Creek Watershed have predominantly silt-sized sediment, so very high sediment transport rates can be expected for sediment eroded from those soils where furrow slopes are about 1% and steeper.

The presence or absence of rainfall did not affect the transport of sand-sized sediment very much. Earlier research on cohesive soils indicated that rainfall would double the rate of erosion from rills of 6% steepness (Meyer, et al., 1975a).

The results of this research show that the transport of sediment along crop row furrows can be greatly influenced by row steepness, row length, and sediment size characteristics. Such influences can therefore greatly affect the amount of sediment delivered to the ends of cropped agricultural fields and into the stream systems where the runoff flows. Since the rates of interrill erosion are very high for the soils of the Goodwin Creek Watershed and since the sediment sizes of the Watershed soils are predominantly the easily transported silts, the potential for delivery of large rates of sediment to the stream system is very high. To reduce the delivery of such sediment, soil conservation practices on intensively cropped fields and/or sediment basins at the ends of such fields to trap the sediment are commonly recommended methods. They certainly seem desirable for intensively cropped land in this Watershed. The loss of such sediment is a problem both downstream where it may deposit in locations where it is not wanted, and on the upland fields where its loss reduces the productive potential of the land from which it was eroded.

4 CONCLUSIONS

4.1 SOIL EROSION

1. Different soils may vary considerably in their rate of erosion due to inherent physical and chemical characteristics.
2. For the Goodwin Creek Watershed soils, the difference in interrill erodibility decreases with increased rainfall duration.
3. The amount and type of vegetative cover greatly influences the rate of erosion from all soils.
4. Prior land use affects the erodibility of a given soil. In particular, soils that have been tilled are more erodible than those that have no recent history of tillage.
5. Apparently, a soil's susceptibility to erosion decreases through the cropping season because of physical or chemical change within the soil.
6. The rate of erosion from woodland or good pasture is very small compared to cultivated areas.
7. The effect of rain intensity (I) on erosion rate (E) can be expressed as $E = aI^b$ for a wide range of soil and cropping conditions. The exponent b is near 2 for soils with low clay contents, so the equation $E = cI^2$ represents these soils quite well.

4.2 SEDIMENT SIZES

8. Sizes of sediment eroded from row sideslopes varied considerably from soil to soil.
9. Much of the sediment eroded from cohesive soils was in the form of aggregates, and some of the aggregates were much larger than the primary particles of which the soils were composed.
10. Sediment size characteristics did not vary directly with those of the primary particles. Finer soil usually produced coarser sediments due to greater aggregation.
11. Sediment size characteristics did not seem correlated with the interrill erodibility rates of soils.
12. Sediment size distributions varied only slightly with major differences in rainfall intensity.
13. Sediment size distributions changed relatively little with continued erosion, at least over a period of a few days.

14. Sediment size distributions changed relatively little with the presence or absence of crop canopy.
15. Soil with a history of cultivation produced finer sediment than the same soil that had not been in cultivation for many years and finer still than for the same soil with no history of cultivation.
16. The relatively small changes in sediment size distributions with major changes in rainfall intensity, storm duration, and canopy suggested that the size distribution of sediment from interrill erosion is a fairly distinct characteristic of a given soil in a given condition.

4.3 TRANSPORT OF ERODED SEDIMENT

17. The capacity of runoff to transport sand-sized sediment along crop row furrows and other flow channels increased rapidly as furrow steepness increased. At steepnesses greater than 1%, large amounts of sediment could be transported.
18. Transport capacity also increased as the flow rate increased, but the effect was less than for furrow steepness.
19. Transport capacity decreased as particle size increased.
20. Generally, rainfall did not effect the rate of sediment transport for the conditions, devices, and techniques studied.

5 BIBLIOGRAPHY

1. American Society of Civil Engineers, 1975. Sedimentation engineering, ASCE Manual No. 54, 745 p.
2. Barnett, A. P., A. E. Dooley and G. A. Smith. 1978. Soil erosion and sediment movement under sugarcane culture in the flatlands of southern Louisiana. Trans. ASAE 21(6):1144-1150, 1156.
3. Bowie, A.J., 1980. Channel contributions to sediment yields in complex watersheds. Presented at ASAE annual meeting, San Antonio, Texas, June 17, 1980. ASAE paper No. 80-2031. Scheduled for pub. Trans. ASAE 1981.
4. Bennett, H. H. 1939. Soil Conservation. McGraw-Hill Book Co., Inc., N. Y.
5. Coleman, N. L., 1967. A theoretical and experimental study of drag and lift forces on a sphere resting on a bed of similar spheres. 12th Cong., IAHR, Ft. Collins, Colorado.
6. DeCoursey, D. G. and L. D. Meyer, 1976. Philosophy of erosion simulation for land use management. In Soil Erosion: Prediction and Control, Soil Conserv. Soc. Amer., Special Pub. 21, 193-200.
7. DeCoursey, D. G. 1980. Runoff, erosion, and crop yield simulation for land use management. Trans. ASAE. Vol. 23, No. 2, pp. 379-386.
8. Doty, C. W. and C. E. Carter. 1965. Rates and particle-size distributions of soil erosion from unit source areas. Trans. ASAE 8(3):309-311.
9. Ekern, P. C. 1950. Raindrop impact as the force initiating erosion, Soil Sci. Soc. Amer. Proc., 15, 7-10.
10. Ellison, W. D. 1947. Soil erosion studies. Agri. Engin., 28, 145-146, 197-201, 245-248, 297-300, 349-351, 402-405, 442-444.
11. Fortier, S., and F. C. Scoby, 1926. Permissable canal velocities. Trans. ASCE, Vol. 89.
12. Foster, G. R., L. D. Meyer and C. A. Onstad. 1977. A runoff erosivity factor and variable slope length exponents for soil loss estimates. Trans. ASAE, Vol. 20, No. 4, pp. 683-687.

13. Foster, G. R., L. J. Lane, J. D. Nowlin, J. M. Laflen and R. A. Young. 1980. A model to estimate sediment yield from field-sized areas: development of model. In CREAMS, a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. USDA-SEA Conservation Research Report No. 26, Vol. I:36-64.

14. Gabriels, D. and W. C. Moldenhauer. 1978. Size distribution of eroded material from simulated rainfall: effect over a range of texture. Soil Sci. Soc. Am. J. 42(6):954-958.

15. Grissinger, Earl H., 1966. Resistance of selected clay systems to erosion by water; Water Resources Research, U.S.D.A. Sedimentation Lab., Oxford, Mississippi.

16. Guy, H. P. 1969. Laboratory theory and methods for sediment analysis. U. S. Geological Survey Book 5, Chapter C1:23-30.

17. Inman, L. Douglas, 1944. Sorting of sediments in the light of fluid mechanics, J. Sedimentary Petrol., Vol. 19, No. 2, pp. 51-70.

18. Kalinske, A. A., 1947. Movement of sediment as bed-load in rivers. Trans. AGU, Vol. 28, No. 4.

19. Kemper, W. D. and W. S. Chepil. 1965. Size distribution of aggregates, Methods of Analysis, Am. Soc. of Agron., Chapter 39:499-510.

20. Laflen, J. M., J. L. Baker, R. O. Hartwig, W. F. Buchele and H. P. Johnson. 1978. Soil and water loss from conservation tillage systems. Trans. ASAE 21(5):881-885.

21. Lattanzi, A. R., L. D. Meyer and M. F. Baumgardner. 1974. Influence of mulch rate and slope steepness on interrill erosion. Soil Sci. Soc. Amer. Proc. 38, 946-950.

22. Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. San Francisco: Freeman, 522 p.

23. Lowdermilk, W. C. 1950. Conquest of the land through seven thousand years. SCS MP-32, 38 p.

24. Meyer, L. D. and E. J. Monke. 1965. Mechanics of soil erosion by rainfall and overland flow. Trans. ASAE, 8, 572-577, 580.

25. Meyer, L. D. and W. H. Wischmeier. 1969. Mathematical simulation of the process of soil erosion by water. Trans. ASAE, 12, 754-758, 762.

26. Meyer, L. D., G. R. Foster and S. Nikolov. 1975a. Effect of flow rate and canopy on rill erosion. Trans. ASAE 18(5): 905-911.
27. Meyer, L. D., G. R. Foster and M. J. M. Romkens. 1975b. Source of soil eroded by water from upland slopes. Proc. of the 1972 Sediment Yield Workshop, Oxford, MS, ARS-S-40:177-189.
28. Meyer, L. D., D. G. DeCoursey and M. J. M. Romkens. 1976. Soil erosion concepts and misconceptions. Proc. Third Federal Inter-Agency Sedium.(?) Conf., Denver, Colorado, Symposium, 2, 1-12.
29. Meyer, L. D. and W. C. Harmon. 1979. Multiple-intensity rainfall simulator for erosion research on row sideslopes. Trans. ASAE 22(1):100-103.
30. Meyer, L. D. 1980. How rain intensity affects interrill erosion. Presented at the 1980 ASAE Winter Meeting. Paper No. 80-2503.
31. Meyer, L. D., W. C. Harmon and L. L. McDowell. 1980. Sediment sizes eroded from crop row sideslopes. Trans. ASAE. 23, 891-898.
32. Mihara, Y. 1951. Raindrops and soil erosion, Natl. Inst. Agri. Sci., Tokyo, Japan, Bull. Ser. A., 76 p.
33. Partheniadas, E., 1971. Erosion and deposition of cohesive materials in H. W. Shen, ed., River Mechanics. Ft. Collins, Colorado: H. W. Shen, 25-1 to 25-19.
34. Piest, R. F. and R. G. Spomer. 1968. Sheet and gully erosion in the Missouri Valley Loessial region. Trans. ASAE. pp. 850-853.
35. Piest, R. F. and A. J. Bowie. 1974. Gully and streambank erosion, Proc. 29th Annual Meeting, Soil Conservation Soc. of America, Syracuse, N. Y., 188-196.
36. Rowlison, D. L. and G. L. Martin. 1971. Rational method for describing slope erosion, Journal of Irrigation and Drainage Div., ASCE, 97, 39-50.
37. Stallings, J. H. 1953. Mechanics of water erosion, SCS TP-118, 26 p.
38. Sutherland, A. J. 1967. Proposed mechanism for sediment entrainment by turbulent flow. J. Geophys. Res. Vol. 72, No. 24.
39. Swanson, N. P., A. R. Dedrick and H. E. Weakly. 1965. Soil particles and aggregates transported in runoff from simulated rainfall. Trans. ASAE 8(3):437, 440.
40. Swanson, N. P. and A. R. Dedrick. 1967. Soil particles and aggregates transported in water runoff under various slope conditions using simulated rainfall. Trans. ASAE 10(2):246-247.

41. U. S. Department of Agriculture - SCS, 1963. Soil survey Panola County, Mississippi. 122 p.

42. U. S. Department of Agriculture, 1965. Soil and water conservation needs - A national inventory, USDA Misc. Pub. 971, 94 p.

43. Weakly, H. E. 1962. Aggregation of soil carried in runoff from simulated rainfall. Soil Sci. Soc. Amer. Proc. 26(5):511-512.

44. White, C. M., 1940. The equilibrium of grains on the bed of a stream. Proc. Royal Society of London, Vol. 174A.

45. Willis, Joe C., Coleman, Neil L., Ellis, M. Wilbert. 1972. Laboratory study of transport of fine sand; Jour. of the Hydraulics Div. Proc. I.A.S.C.E., 1972.

46. Wischmeier, W. H. and J. V. Mannering. 1969. Relation of soil properties to its erodibility, Soil Sci. Soc. Amer. Proc., 23, 131-137.

47. Wischmeier, W. H. 1976. Use and misuse of the universal soil loss equation. J. Soil and Water Conserv. 33(1):5-9.

48. Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses - a guide to conservation planning. USDA-SEA Agriculture Handbook 537, 58 p.

49. Yoder, R. E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. J. Am. Soc. Agron. 28:337-351.

50. Young, R. A. and C. K. Mutchler. 1969. Effect of slope shape on erosion and runoff. Trans. ASAE 12(2):231-233, 239.

51. Young, R. A. and C. A. Onstad. 1976. Predicting particle-size composition of eroded soil. Trans. ASAE 19(6):1071-1075.

52. Zuhdi, B. A., 1979. Flume studies of sediment transport in shallow furrow flow with simulated rainfall. A thesis submitted to faculty of the University of Mississippi in partial fulfillment of the requirements for the degree of Master of Science in the Department of Civil Engineering. May, 1979.